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FIRE ENDURANCE TESTING OF FIBERGLASS PIPING

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16. Abstract

The U.S. Coast Guard has conducted fire endurance tests on several types of fiberglass reinforced plastic piping (FGP) as well as other common piping materials.

The test piping, including joints and fittings, was exposed to large hydrocarbon pool fires (Phase 1), propane flames from a multi-burner array (Phase 2), and simulated localized machinery space fires (Phase 3).

Test objectives included the following: (1) to investigate FGP fire endurance under various conditions when exposed to large hydrocarbon fuel fires, (2) to evaluate FGP fire endurance test methods being considered by the International Maritime Organization (IMO) , (3) to obtain temperature and heat flux data representative of real shipboard fires involving hydrocarbon fuels, and (4) to compare the fire endurance of FGP with that of other common piping materials in the same fire conditions.

Conclusions derived from the tests include (1) joints are the weakest link in FGP systems, (2) seal failure caused by a fire can destroy the integrity of FGP or metal piping even though the pipe itself remains intact, and (3) when FGP contains flowing water, its fire endurance can be increased significantly.

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METRIC CONVERSION FACTORS

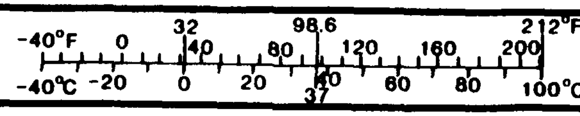
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The Coast Guard Research and Development Center expresses its appreciation to Ameron Fiberglass Pipe Division and Smith Fiberglass Products, Inc. for providing piping, couplings and expertise which led to the successful accomplishment of this test program. The tests described in this report are part of a continuing marine fire safety research program planned and conducted by the United States Coast Guard with the participation and cooperation of private industry to save lives and protect property.

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1.0 INTRODUCTION

There is great interest in replacing steel pipe with fiberglass-reinforced plastic pipe (FGP) in commercial vessel and warship piping systems. In many of these systems, FGP appears to offer substantial savings in weight and cost over the operating life of the vessel. However, there is concern regarding the fire resistance of FGP. Considerable caution must therefore be used in establishing the criteria for determining FGP's acceptability for specific applications.

United States Coast Guard guidelines for the use of FGP are contained in Navigation and Vessel Inspection Circular (NVIC) 11-86 (Reference 1) which was issued in 1986. Enclosure (1) of this NVIC contains general design and installation requirements for FGP systems on Coast Guard-inspected vessels. It also contains a listing of specific applications in which FGP is considered to be acceptable, and a second listing of unacceptable applications. NVIC 11-86 states that in order for FGP to replace steel pipe in systems from which it is currently prohibited, it must be shown that the fire endurance of the FGP, as installed, is equivalent to that of steel pipe.

Equivalency to steel pipe is to be demonstrated by subjecting FGP samples to a one hour fire test at 1700°F (927°C). Three samples must be tested: one empty, one partially filled with fluid, and one completely filled. After the test, each pipe should be capable of withstanding a hydrostatic pressure equal to its rated pressure without failure or appreciable leakage. Equivalency does not have to be demonstrated unless it is proposed that FGP be used in an application specifically prohibited by Section 3.b of NVIC 11-86. It is recognized that fire resistance may be a relatively minor consideration for some FGP applications.

There is a great variety of possible shipboard applications of fiberglass pipe, and approval for its use should be evaluated on a system by system basis. This approval would take into account not only the fire resistance of the piping material, but also the consequences of a loss of system integrity.

Questions arose concerning how stringent the acceptance criteria for FGP should be. In most cases, FGP was being proposed as a replacement for steel pipe. It was therefore reasoned that if a fire occurred, the FGP did not have to outlast the steel piping. This in turn focused attention on the question of how severe a fire exposure the piping systems should be able to survive. It should be pointed out that although the steel piping might be able to withstand a fire for a very long time, system integrity would be maintained only for as long as the piping joints, the gaskets and the pipe supports lasted.

Rather than adopting a single temperature/duration criteria test for all FGP shipboard piping, regulatory groups have pursued the concept of graded levels of fire endurance. Each level would represent the requirements appropriate for a different type of piping system and/or a different location aboard ship. The principal factors to be considered in establishing the different levels of fire resistance are:

1. Possible severity of fire and length of time before extinguishment can reasonably be expected.

2. Nature of the fluid contained within the piping (e.g., flammable or nonflammable).

3. Importance of the piping system to the operation or safety of the vessel (e.g., vital or nonvital).

Subsequent to the issuance of NVIC 11-86, the International Association of Classification Societies (IACS) submitted a group of proposed fire protection requirements for plastic piping (Reference 2) to International Maritime Organization (IMO). The IACS acceptance criteria for plastic pipe were based on three levels of fire endurance requirements. These levels were designed to take into account the variation in severity of actual fires, as well as different possible consequences of piping failure resulting from fire. The fire endurance levels proposed by IACS were essentially as follows:

Level 1 (L1): Piping under dry conditions can endure a hydrocarbon fire of long duration without loss of integrity.

Level 2 (L2): Piping under dry conditions can endure a hydrocarbon fire for a shorter, but still appreciable, period without loss of integrity. The duration selected for the L2 test, 30 minutes, was intended to be sufficient "to permit preventive or precautionary actions to be taken."

Level 3 (L3): Waterfilled piping can endure a local fire for an appreciable period without losing its ability to function satisfactorily after the fire has been extinguished.

The IACS proposal also included a table of fire endurance requirements covering a variety of piping systems and locations aboard ship.

The IACS recommended that fire endurance corresponding to Levels 1 and 2 should be demonstrated by testing dry plastic pipe in a temperature-controlled furnace. For Level 3 testing, IACS proposed a test method in which horizontal water-filled pipe is subjected to flames produced by an array of propane burners located below the pipe.

2.0 OBJECTIVE

The objective of this work was to evaluate several fire endurance test methods being considered by the International Maritime Organization for use in establishing the acceptability of fiberglass piping for shipboard systems.

This report covers an extended investigation by the U.S. Coast Guard into the fire endurance of fiberglass piping materials.

The investigation consisted of three test phases. Phase 1 investigated the fire endurance of large diameter piping subjected to a large hydrocarbon liquid pool fire. Phase 2 examined the performance of small diameter piping exposed to flames produced by a propane burner array. This test method was proposed for International Maritime Organization (IMO) consideration by the International Association of Classification Societies (IACS). Phase 3 investigated the performance of small to medium diameter piping exposed to a localized fire in a simulated machinery space.

3.0 PHASE 1 TESTS: Large Hydrocarbon Liquid Pool Fires

3.1 Phase 1 Objectives

The objectives of this test series were (1) to evaluate the endurance of FGP, compared to that of steel pipe, during one hour large hydrocarbon pool fires, and (2) to determine whether large hydrocarbon pool fires are sufficiently reproducible to justify their use as a standardized fire test method.

3.2 Technical Approach

Phase 1 tests investigated the fire endurance of large FGP and steel piping assemblies containing fittings, flanges and simulated valves. These tests simulated on-deck piping runs exposed directly to a large hydrocarbon pool fire. Concurrent with the design of the Phase 1 tests, the American Society for Testing and Materials (ASTM) was developing a test procedure for simulating the effect of large hydrocarbon pool fires on structural members (Reference 3). The proposed ASTM test method was used as a guide in developing portions of the Phase 1 test procedures.

A distinguishing feature of large hydrocarbon pool fires is the rapid development of high temperatures and heat flux. The ASTM test method required that test specimens be subjected to an incident heat flux of 55,000 BTU/sq ft/hr (173,500 W/sq m) and a temperature between 1700°F (927°C) and 2300°F (1260°C). These flux and temperature levels are to be reached within the first five minutes and maintained for the remaining 55 minutes of the one hour test.

The ASTM test method was used as a guide instead of the IMO Standard Fire Test (Chapter II-2, Regulation 3 of Reference 4) because the latter is intended for simulating interior fires which are ventilation-controlled and not as intense as a hydrocarbon pool fire.

3.3 Test Setup

Phase 1 testing was conducted at the U.S. Coast Guard Fire & Safety Test Detachment in Mobile, Alabama. The fire tests were run aboard the test vessel ALBERT E. WATTS at Little Sand Island.

Steel coamings were erected on the main deck to form a fire test pan 20 feet (6.1 m) long by 12 feet (3.7 m) wide (Figure 3-1). A safety pan was constructed around the fire pan, as a means of containing any fuel or water which might spill or leak from the fire pan. Fire containment barriers, firemain piping, and structural modifications were added to the deck where needed.

Four FGP and four steel pipe assemblies were tested. Each test pipe assembly was 30 feet (9.1 m) long and included three types of fittings (Figures 3-2 and 3-3). Each fire test involved a fiberglass pipe assembly and a similar steel pipe assembly with the same nominal pipe diameter. The two assemblies were supported horizontally, parallel to each other above the center of the fire pan, and approximately one foot (0.3 m) apart (Figure 3-4). The ends of the pipe assemblies extended 5 feet (1.5 m) beyond the fire pan coamings on each side. Supports for the pipe assemblies were located both inside and outside the fire pan. In the fire pan, the supports were 15 feet (4.6 m) apart.

3.4 Test Specimens

The test specimens included four 10-inch pipe assemblies (two steel and two FGP) and four 8-inch pipe assemblies (two steel and two FGP). None of the pipes or fittings were protected with insulation. Fabrication of all fiberglass pipe assemblies was directed and supervised by a representative of the fiberglass pipe manufacturer.

Two types of epoxy fiberglass piping were tested. The 10-inch piping (Tests 1 and 2) consisted of filament-wound fiberglass epoxy resin pipe with conductive filaments (carbon fibers) in the pipe wall to prevent the buildup of static electrical charges. The piping was light brown with black strands visible. The 8-inch piping (Tests 3 and 4) consisted of filament-wound fiberglass epoxy resin pipe with a 0.02-inch (0.5 mm) integral resin-rich epoxy liner. It did not contain the conductive filaments, and was black in color.

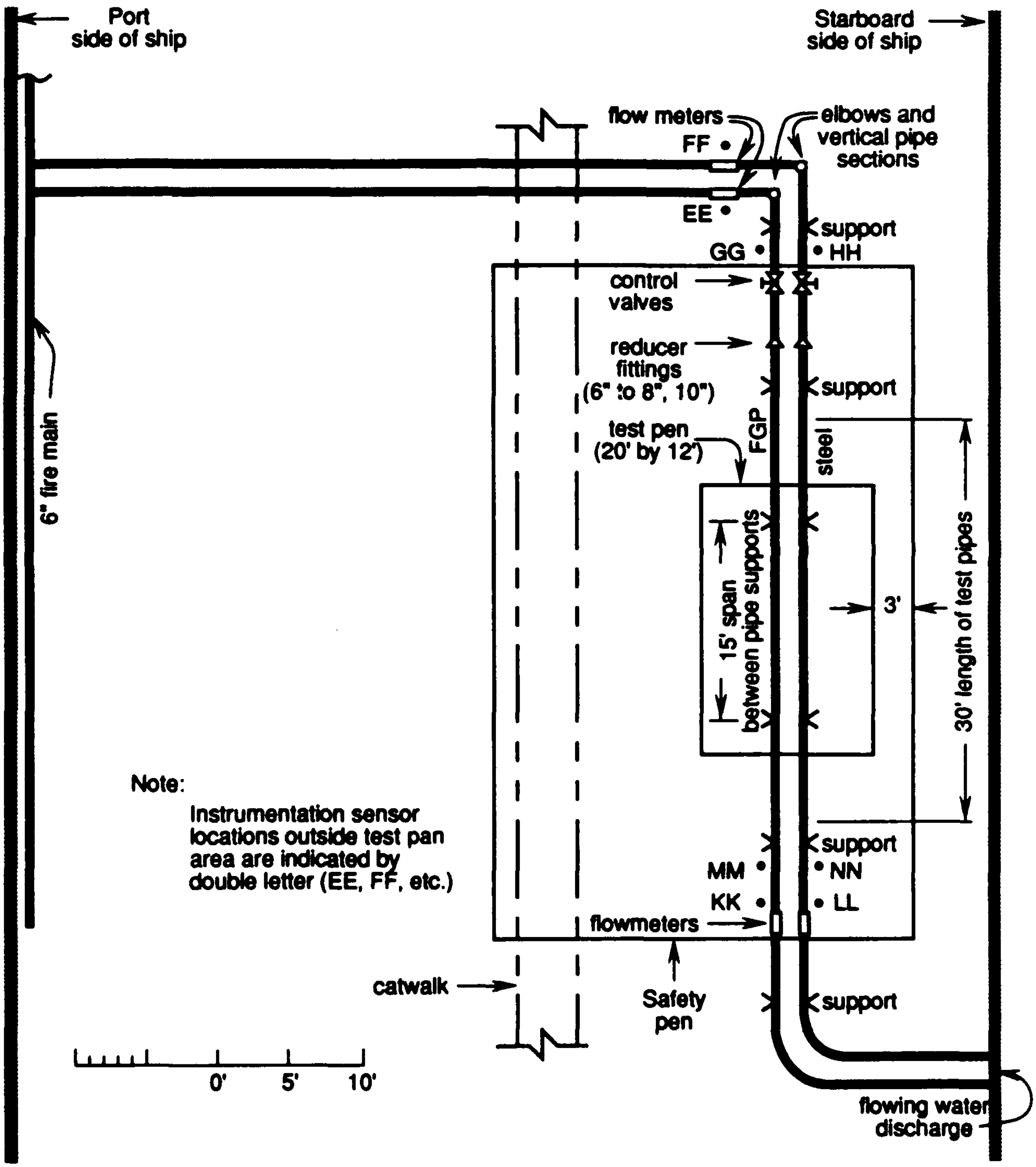


Figure 3-1 General Arrangement and Sensor Locations

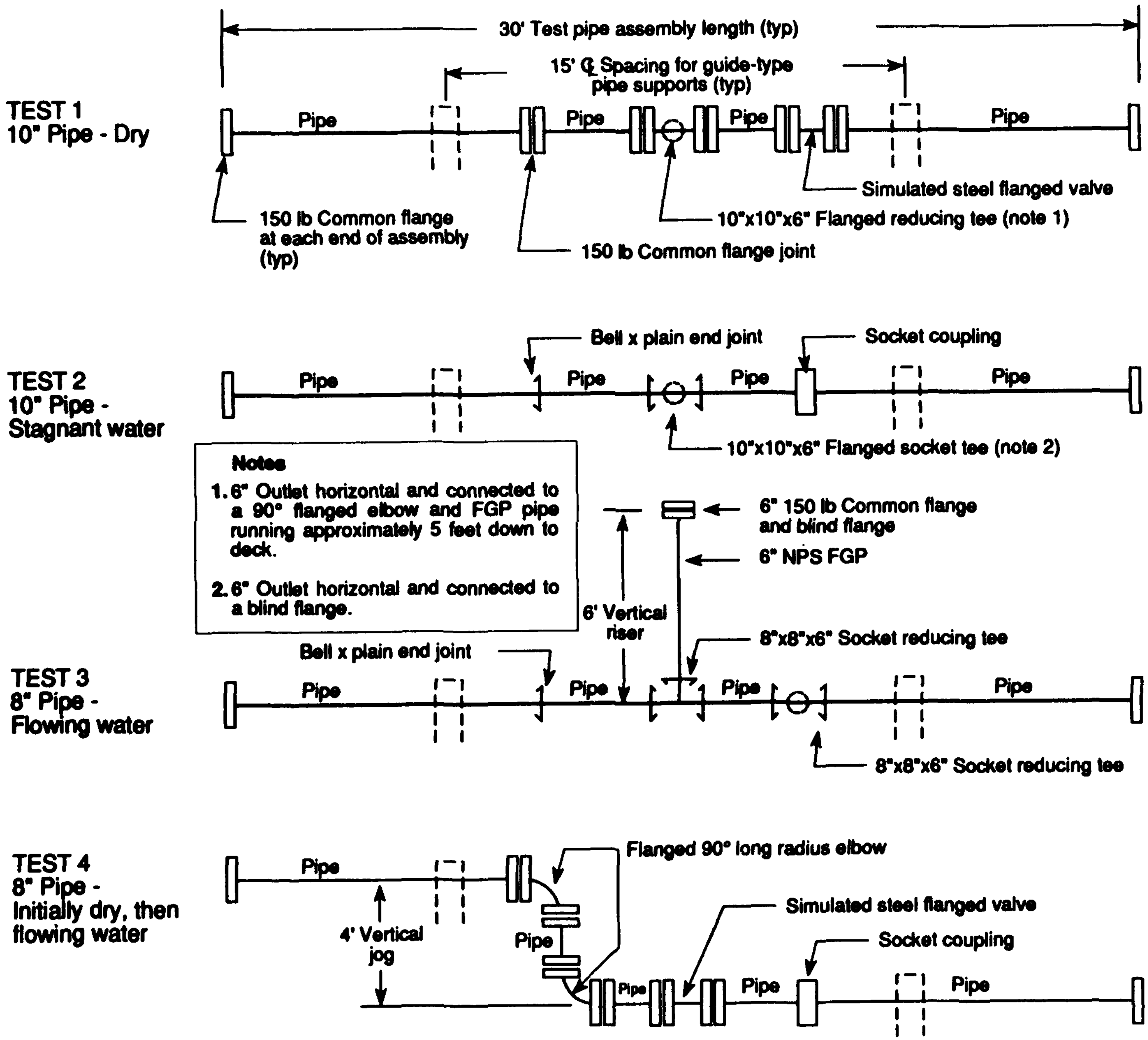


Figure 3-2 FGP Test Pipe Assemblies

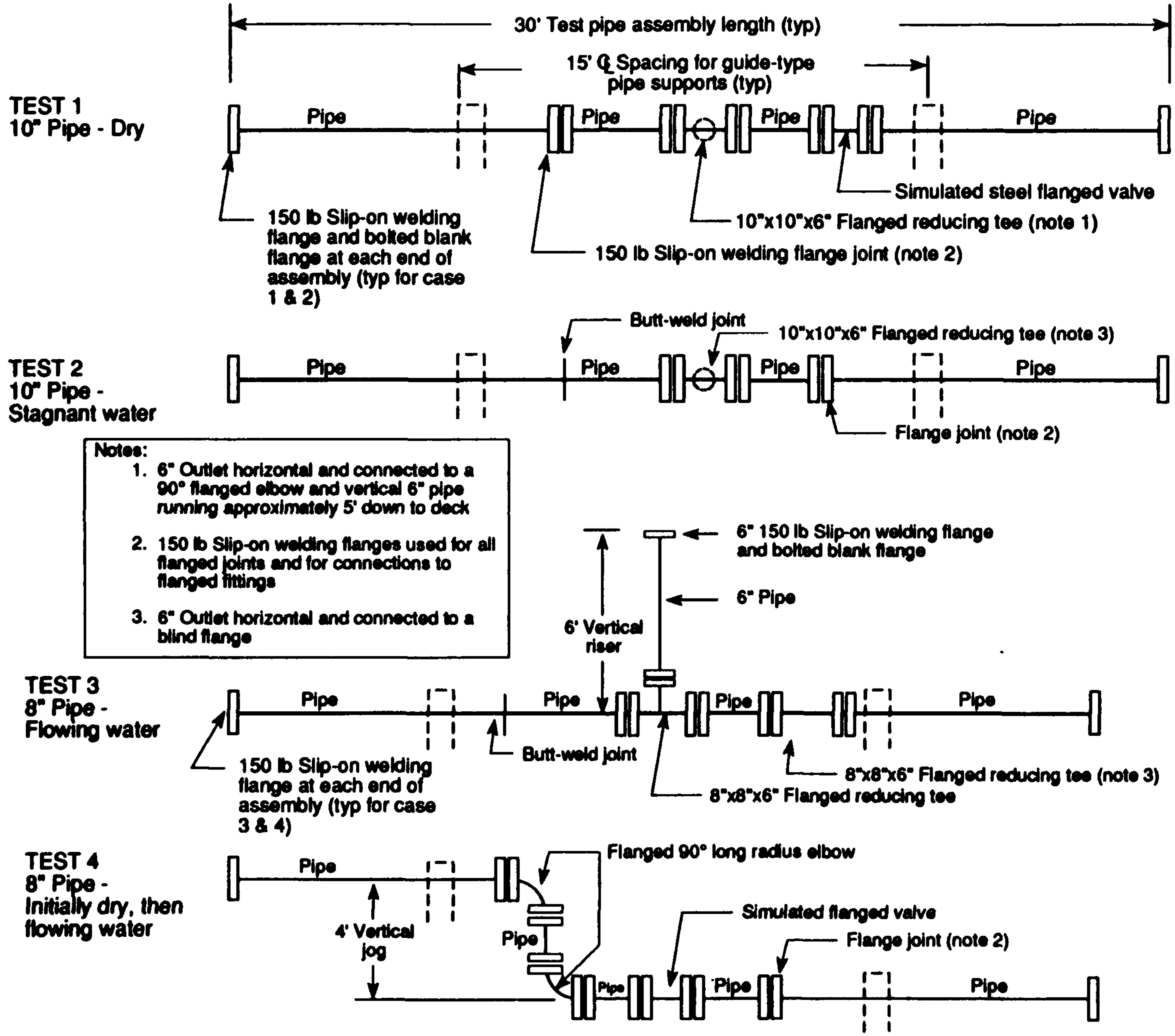
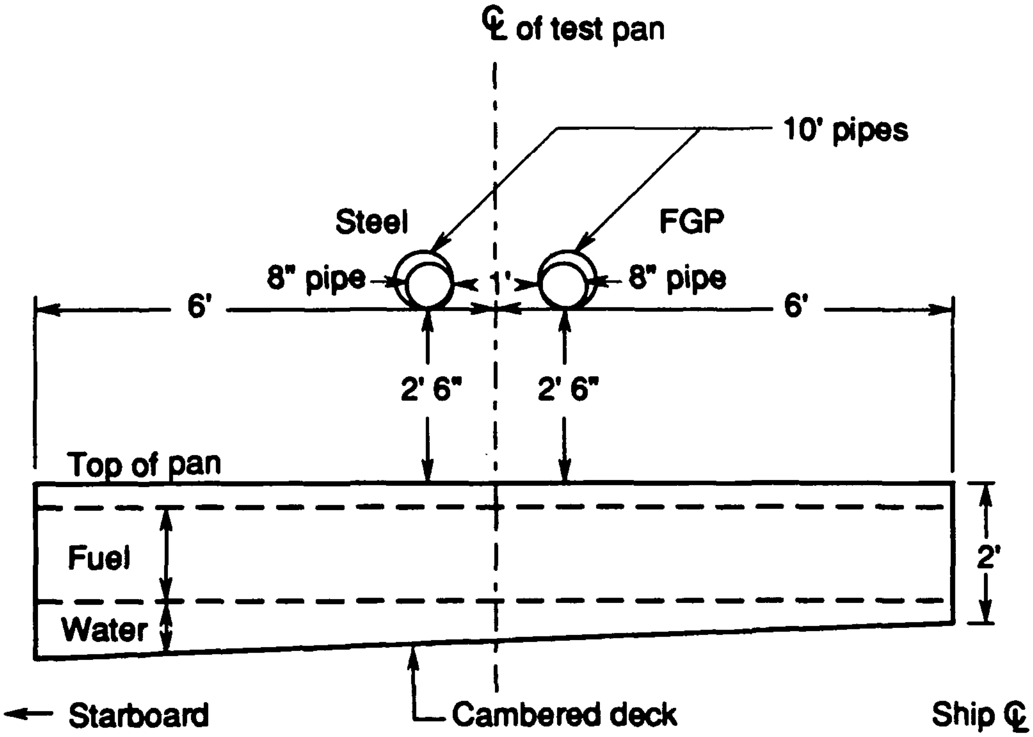


Figure 3-3 Steel Test Pipe Assemblies



Test Scenario		Pipe Diameter
Test 1	Dry (pressurized)	10"
Test 2	Full of stagnant water	10"
Test 3	Flowing water	8"
Test 4	Dry / flowing water	8"

FIGURE 3-4 Location of Test Pipes Above Fire Pan (End View)

Fittings incorporated into the test pipe assemblies included flanges, socket and spigot couplings, flanged elbows, flanged reducing tees, socket reducing tees, and simulated valves. The pipe and fittings were rated for 150 psi (1034 kPa) operating pressure.

The steel piping was Schedule 40 ASTM Specification A53 Grade B pipe. Steel slip-on welding flanges were ASTM Specification A105, 150-pound class. Standard Grade 5 bolts were used in the flanges. One-eighth inch (3 mm) thick marine gaskets (composed of 80% chrysotile asbestos encapsulated in synthetic rubber) were placed between the flanges.

Additional information on the pipes and fittings is included in Appendix A.

3.5 Instrumentation

Ambient conditions were measured during every test. These included wind direction, wind speed, barometric pressure, and ambient temperature. Thermocouples were used to measure temperatures in the flames and on the piping. Calorimeters were used to measure incident heat flux experienced by the piping. The gas velocity of the flames near the piping and the oxygen concentration around the piping were also measured in each test. The flow rate and temperature of the water in the pipes were also measured. The internal pressure buildup was measured in the pipes for tests 1 and 2. Relief valves were installed in the end of these pipes to prevent an explosion. A computer data acquisition system was used to record the various channels of test data.

Color video cameras, an infrared camera, and 35 mm cameras were used to document the tests. Time-date generators were used with the video recordings.

3.6 Procedures

Marine diesel fuel oil was used as the test fuel. Fresh fuel was used in each test. The fuel was floated on top of a layer of water inside the test pan. The water layer, which was at least 6 inches (152 mm) deep, protected the ship's deck from heat and flame damage. Three hundred gallons (1135 liters) of fuel were used in a pretest. For Tests 1 through 4, the amounts of fuel were 1200, 1500, 1700 and 1700 gallons (4540, 5680, 6435 and 6435 liters), respectively. In each test, 20 gallons (76 liters) of mineral spirits were added prior to ignition to promote rapid burning across the fuel surface.

Since these tests were run outdoors, it was necessary to limit the effect of wind conditions as much as possible. Therefore, tests were not begun if wind velocity exceeded 5 miles per hour (2.2 m/sec).

A pretest fire was conducted prior to Test 1 to ensure that all instrumentation was functioning properly and to insure that the proper heat flux was being produced.

Conditions of the pipes for the four tests were as follows:

Test 1 (10-inch pipe, dry): Both pipes were initially pressurized with air at 13 psig (90 kPa).

Test 2 (10-inch pipe, stagnant water): Both pipes were filled with water and then pressurized at 20 to 25 psig (138 to 172 kPa).

Test 3 (8-inch pipe, flowing water): Both pipes were full of flowing water; the flow rate through each pipe was 210 to 260 gallons per minute (795 to 984 lpm) at a pressure of 4 to 10 psig (28 to 69 kPa).

Test 4 (8-inch pipe, mixed conditions) The fiberglass pipe was filled with stagnant water and then pressurized at 13 psig (90 kPa). The steel pipe was dry (full of unpressurized air) for the initial 20 minutes of the test; during the remainder of the test, the pipe was full of flowing water (210 to 260 gallons per minute) (795 to 984 lpm).

3.7 Results

The test results are summarized in the following paragraphs. Timing of events is expressed as Test Time (TT), which is the elapsed time (minutes: seconds) between ignition of the test fuel and the observed event.

Pretest:

Within one minute after ignition, the flames had spread across the entire fuel surface inside the test pan. Full flame involvement inside the pan lasted for 17 minutes, during which flame temperatures of 2370°F (1300°C) were recorded. Heat from the fire was sufficient to cause buckling of the deck plating adjacent to the walls of the pan. The high flux readings indicated that calorimeters located in the flames would have to be cooled and insulated to avoid damage.

Test 1: (10-inch pipe, dry)

The FGP lost pressure at approximately TT 2:00. The middle tee fitting collapsed at TT 3:00. Glue in two FGP joints deteriorated thus allowing the pipe to pull out of the joint and collapse in the fire pan. The FGP suffered moderate to severe damage at all of the remaining 11 joints. The FGP was so severely damaged from the fire that it could not be pressure-tested. The steel pipe lost pressure at TT 10:40, but remained intact. Because of damage to its joint gaskets, the steel pipe would not hold pressure after the fire test.

Test 2: (10-inch pipe, stagnant water)

The 6-inch FGP pipe separated from the 10" x 6" (254 mm x 152 mm) reducer bushing at the tee fitting at TT 4:00. Internal pressure in the FGP was approximately 50 psig (345 kPa) when separation occurred. Two other joints also failed later in the fire; in each case failure occurred when the pipe pulled horizontally out of the joint. The steel pipe remained intact throughout the test. At TT 16:34, a joint gasket in the steel pipe failed, relieving the internal pressure.

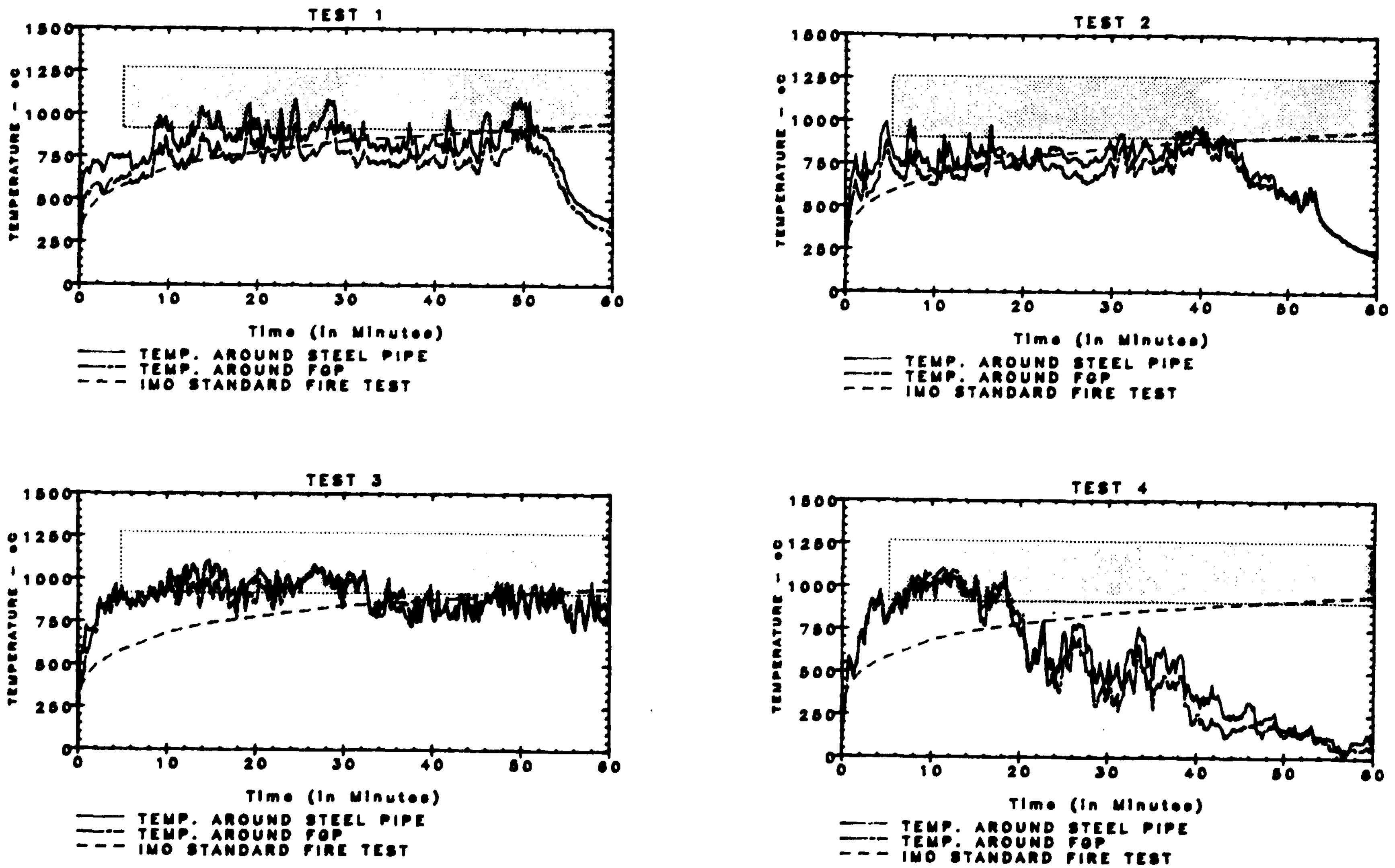
Test 3: (8-inch pipe, flowing water)

The FGP remained inplace during the entire test. Leakage occurred at the FGP tee at TT 29:00. Shortly thereafter the outer layers of the FGP began delaminating. During the post-fire pressure test, the reducer bushing at the tee was forced out of the joint when the internal pressure reached approximately 20 psig (138 kPa). The steel pipe remained intact during the entire test, with no visible damage and no leakage at the flange gaskets.

Test 4: (8-inch pipe, mixed conditions)

The FGP lost pressure at TT 1:15. At TT 6:00 the upper horizontal section collapsed, followed by the vertical section at TT 12:00. None of the FGP fittings failed by pulling apart longitudinally. The steel pipe remained intact during the entire test. Almost immediately after water flow began in the steel pipe (at TT 20:00), leakage occurred at all the flanged joints in the horizontal sections of the pipe. (No leakage was observed in the vertical pipe sections).

Flame temperatures above the middle of the test pipes are plotted in Figure 3-5 for Tests 1 through 4. The data shows that there was a considerable difference in sustained temperature levels for these four tests. Part of the variation can be



Note: Shaded area represents proposed ASTM limits (reference 3)

Figure 3-5 Flame Temperatures (Tests 1-4) attributed to relatively small changes in wind speed and direction between the tests (all of which were conducted under low-wind conditions).

Heat flux data is shown in Figure 3-6. The calorimeters were destroyed early in the pretest fire due to failure of the calorimeter water cooling system.

4.0 PHASE 2 TESTS: IACS Propane Burner Assembly

4.1 Phase 2 Objective

The objective of the Phase 2 testing was to evaluate the fire endurance test method proposed by the International Association of Classification Societies (IACS) (Reference 2) to determine its suitability as a Level 3 fire endurance test for water-filled piping. The test method had been considered for adoption by the International Maritime Organization (IMO) as a standard test method.

According to Reference 2, a Level 3 fire endurance "is considered to provide fire endurance necessary for a water filled piping system to survive a local fire for a period sufficient to allow fire extinguishing systems to be activated. The objective of requiring such a fire endurance standard is to enable restarting a system after a fire has been put out".

Specific objectives of the Phase 2 tests were as follows:

a. Determine whether the test apparatus can be set up and operated as specified in the IACS test method.

b. Determine whether a propane flow rate of 5 kg (11 lb) per hour (as specified in the IACS test method) produces the required heat output from the test apparatus.

c. Determine whether the test method is suitable for large diameter pipes.

d. Determine the effect of pipe support conditions on fire endurance (i.e., compare the results for the case where the pipe is fixed at one support and free at the other with results for the case where the pipe is fixed at both supports).

e. Determine whether water leakage from the test pipe can be measured satisfactorily during the fire tests.

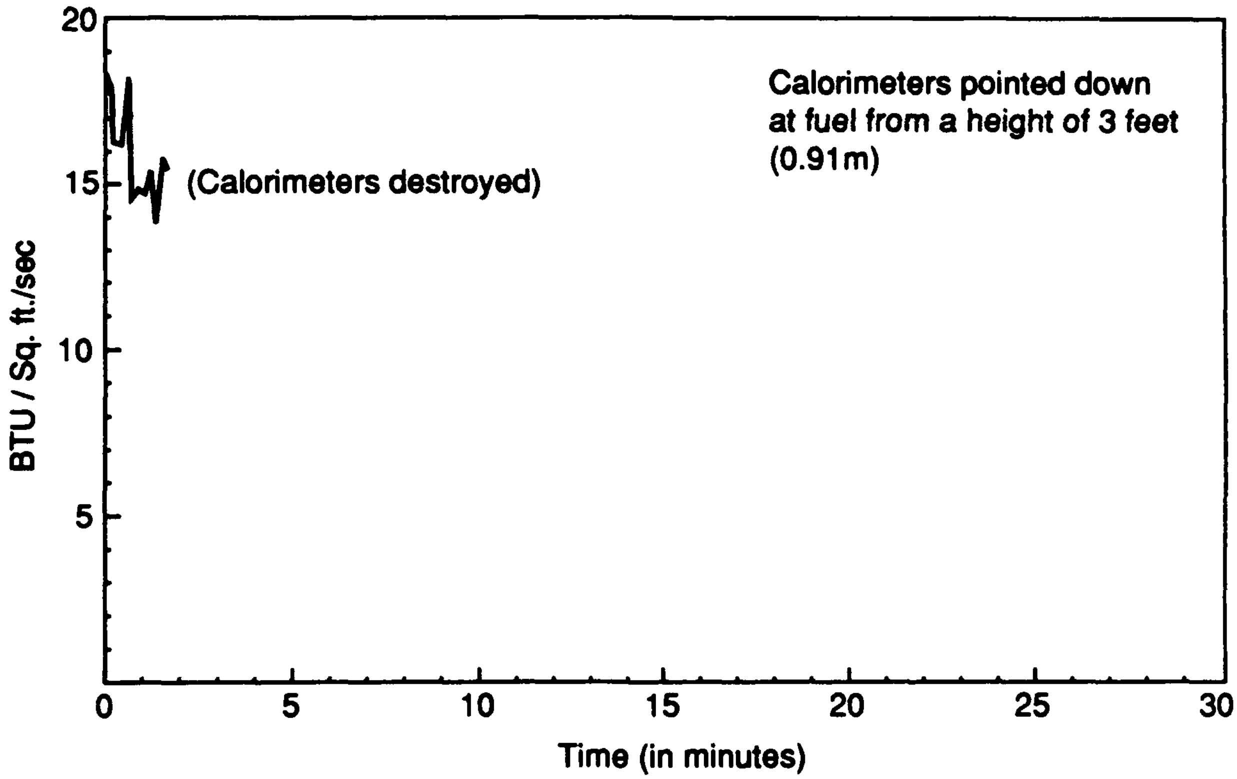


FIGURE 3-6 Pool Fire Test Average Heat Flux

4.2 Technical Approach

The burner array described in the proposed IACS Level 3 fire endurance test method (Figure 4-1) was assembled, together with other necessary apparatus, at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama.

Calibration tests were made without piping samples to obtain time-temperature data and incident heat flux values at different heights above the burner array. These calibration tests were conducted using the burner fuel flow rate specified by the IACS test method.

Fire tests were conducted on a number of small-diameter (1-, 2-, 3-, and 4-inch nominal pipe size) fiberglass piping samples of various types, with and without couplings. Carbon steel and copper-nickel samples were also tested. Where couplings were used, they were positioned directly above the burner array to simulate worst-case conditions.

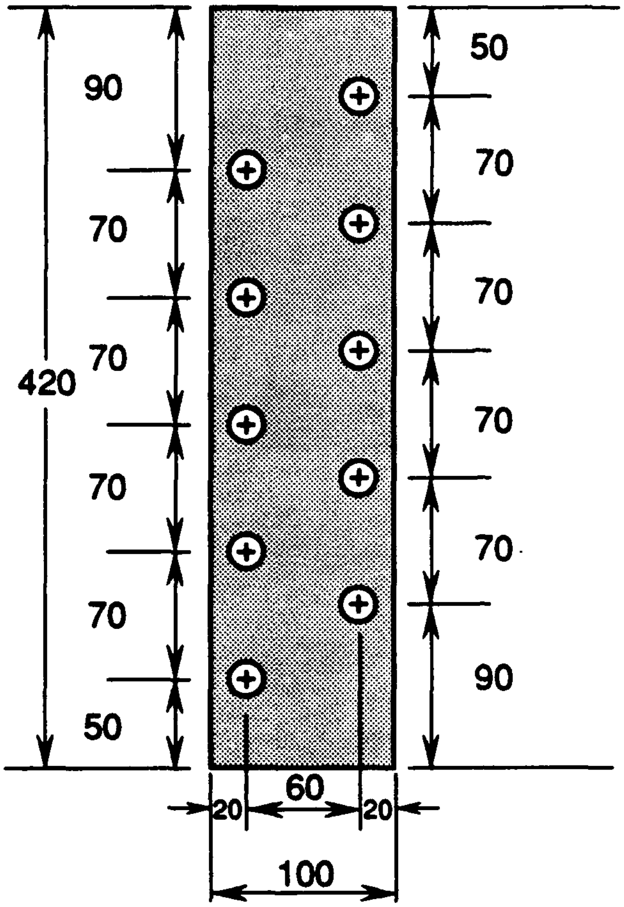
Seven calibration tests without piping and 21 fire tests with piping were conducted.

4.3 Test Setup

The burner array was fabricated and set up as described in the proposal which IACS had submitted to IMO (Reference 2). The array consisted of ten individual propane burners (Sievert No. 2942) connected to a manifold, as shown in Figure 4-1. Since the burner design did not include an integral control valve for adjusting individual flame heights, a needle valve was installed for this purpose between each burner and the manifold. The burners were installed in the manifold in two rows of five burners, as shown in Figure 4-1. The layout of the test apparatus is shown schematically in Figure 4-2.

The IACS test method specifies that propane (minimum purity of 95 percent) be used as the burner fuel and that the total heat output from all ten burners be maintained at 65 kW (221,800 BTU/hr) corresponding to a total propane flow rate of 5 kg (11 lb) per hour). The test method requires that propane consumption be measured to an accuracy of +/- 3 percent. The fuel system used for these tests consisted of a propane tank suspended from a load cell weight monitoring system, and a fuel supply piping system which included a manual regulator valve and a flowmeter.

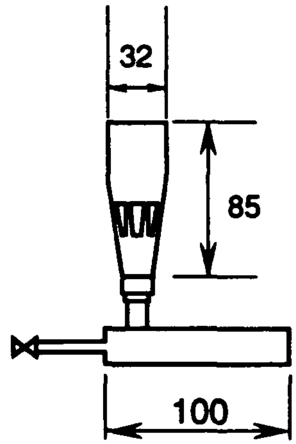
For the tests, each pipe specimen was supported directly above the centerline of the burner array and parallel to the burner rows. The two pipe specimen mounts were spaced 32 inches (813 mm) apart in accordance with the IACS test method. The specimen mounts were arranged so as to maintain the distance between the top of the burners and the bottom of the test



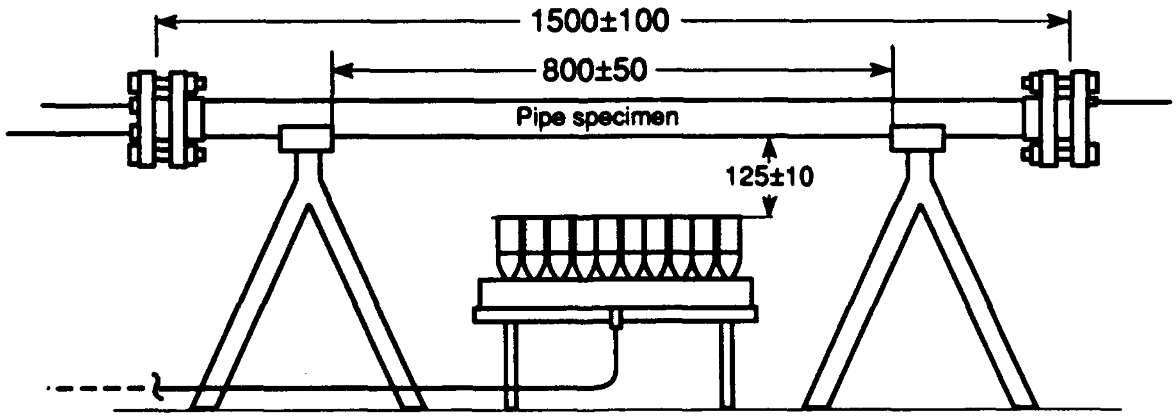
Top View

Reproduced from IACS Test Procedure; all dimensions are in millimeters.

All burners are Sievert No. 2942, as specified in reference 2.

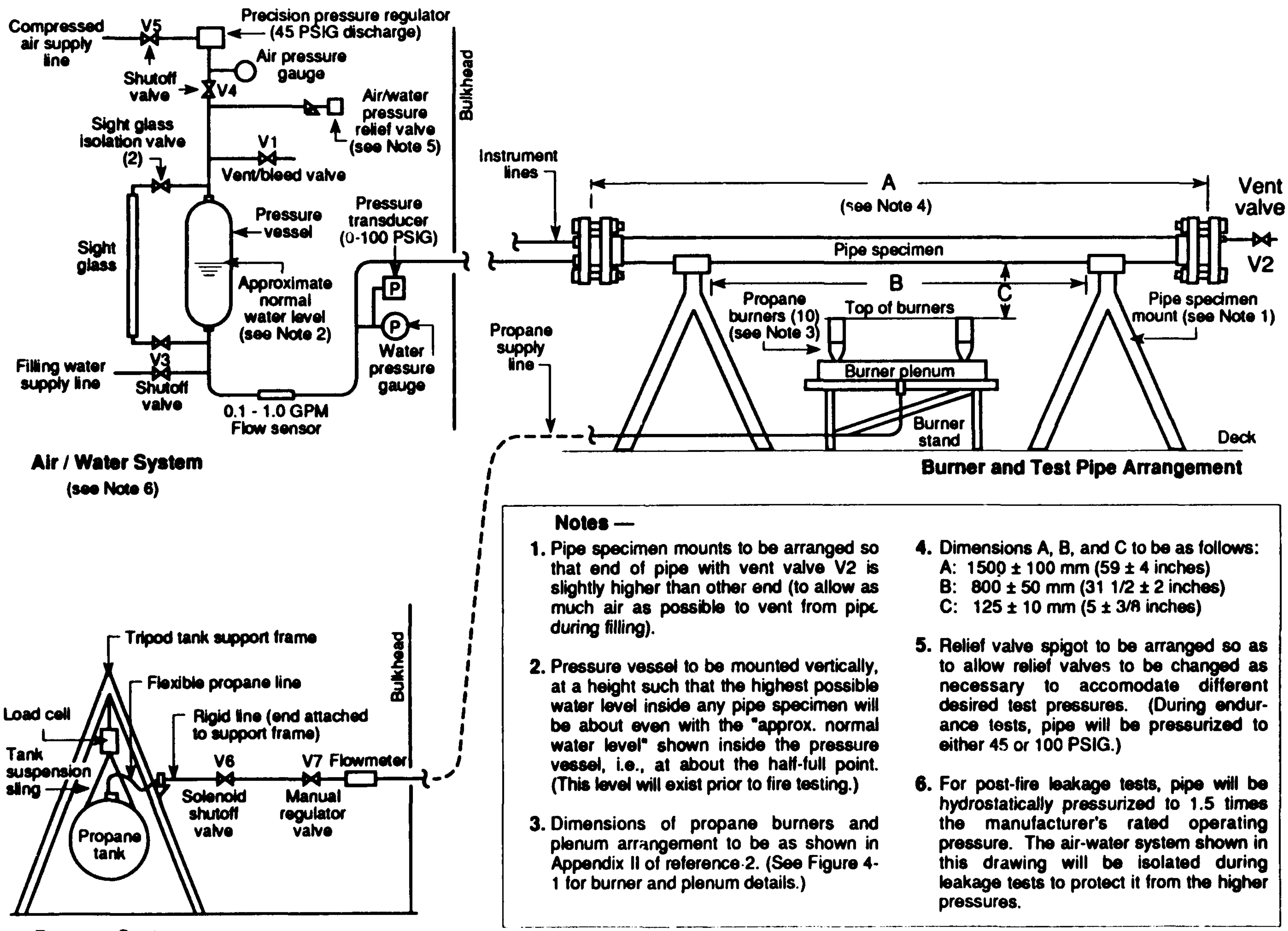


Side View of One Burner



Piping / Burner Setup

Figure 4-1 Fire Endurance Test Burner Assembly



Notes —

1. Pipe specimen mounts to be arranged so that end of pipe with vent valve V2 is slightly higher than other end (to allow as much air as possible to vent from pipe during filling).

2. Pressure vessel to be mounted vertically, at a height such that the highest possible water level inside any pipe specimen will be about even with the "approx. normal water level" shown inside the pressure vessel, i.e., at about the half-full point. (This level will exist prior to fire testing.)

3. Dimensions of propane burners and plenum arrangement to be as shown in Appendix II of reference 2. (See Figure 4-1 for burner and plenum details.)

4. Dimensions A, B, and C to be as follows:
   A: 1500 ± 100 mm (59 ± 4 inches)
   B: 800 ± 50 mm (31 1/2 ± 2 inches)
   C: 125 ± 10 mm (5 ± 3/8 inches)

5. Relief valve spigot to be arranged so as to allow relief valves to be changed as necessary to accomodate different desired test pressures. (During endurance tests, pipe will be pressurized to either 45 or 100 PSIG.)

6. For post-fire leakage tests, pipe will be hydrostatically pressurized to 1.5 times the manufacturer's rated operating pressure. The air-water system shown in this drawing will be isolated during leakage tests to protect it from the higher pressures.

Figure 4-2 Burner Fire Endurance Test Setup Schematic (not to scale) specimens at 5 +/- 3/8 inches (127 +/- 10 mm), as specified in the test method. The specimen mounts were arranged so as to allow the pipe specimens to be either fixed at one mount and free at the other, or else fixed at both mounts as would be expected in real installations. It should be noted that the IACS proposed test method specifies that the specimens are to rest freely on both supports. It is felt that this would not be a realistic installation method.

A filling and pressurization system was used to completely fill each test pipe with water prior to testing. Compressed air was used to maintain an internal pressure. A sight glass and a flow meter were incorporated into the system to provide visual indication of loss of internal pressure and leakage rate from the pipe during the fire test. A pressure relief valve was included in the system to vent any excessively high internal pressures which might occur during the fire tests.

All tests were conducted indoors to prevent wind conditions from influencing the results.

4.4 Test Specimens

Each pipe sample was 60 inches (1524 mm) long with a flange at each end. The samples were tested in a horizontal position between support stands spaced as described in Section 4-3. Each sample was clamped to one or both of the stands. The ends of each pipe sample were capped; one end was connected to the air/water pressurization system.

Five different piping materials were evaluated in the Phase 2 tests:

Fiberglass reinforced epoxy pipe (Ameron Bondstrand 2000M and Smith Green Thread)

Fiberglass reinforced vinylester pipe (Ameron Bondstrand 5000M and Smith Poly Thread)

Fiberglass reinforced phenolic pipe (Ametek Haveg SP)

Carbon steel

90-10 Copper-nickel alloy

Additional descriptions and dimensional data for each of these materials are included in Appendix B.

As indicated in Table 4-1, several test samples contained couplings. The couplings were located at the middle of the pipe samples and were centered over the burner array during a fire test.

TABLE 4-1 Results of IACS Level 3 Tests on Pipes

Test No.	Pipe Description	Manufacturer's Description	Nominal Pipe Size (inches)	Nominal Pipe Size (mm)	Water Pressure (psig)	Water Pressure (kPa, gage)	Fixed Pipe Support	Time to Water Leakage (min:sec)	Comments**
1	FGP Epoxy	Bondstrand 2000M	2	50	45	310	Both Ends	2:40	Weeping/pool on floor
2	FGP Epoxy	Bondstrand 2000M	2	50	100	690	Both Ends	1:40	Dripping/pool on floor
3	FGP Epoxy	Green Thread	2	50	45	310	One End	1:50	Leaking/solid stream
4	FGP Epoxy	Bondstrand 2000M	4	100	45	310	Both Ends	36:38*	Weeping/as pipe cooled
5	FGP Epoxy	Green Thread	4	100	45	310	Both Ends	23:00	Dripping/steady stream
6	FGP Epoxy	Green Thread	1	25	45	310	Both Ends	1:20	Dripping/pool on floor
7	FGP Epoxy-cplg	Bondstrand 2000M	2	50	45	310	Both Ends	2:15	Weeping/steady dripping
8	FGP Epoxy-cplg	Bondstrand 2000M	2	50	100	690	Both Ends	2:03	Dripping/pool on floor
9	FGP Epoxy-cplg	Bondstrand 2000M	2	50	45	310	One End	2:41	Weeping/steady dripping
10	FGP Epoxy-cplg	Green Thread	2	50	45	310	Both Ends	3:09	Pipe popped free from one end of coupling
11	FGP Epoxy-cplg	Green Thread	2	50	100	690	Both Ends	2:33	Pipe popped free from one end of coupling
12	FGP Epoxy-cplg	Green Thread	2	50	45	310	One End	2:44	Pipe popped free from one end of coupling
13	FGP Vinylester-cplg	Poly Thread	2	50	45	310	One End	1:37	Pipe popped free from one end of coupling
14	FGP Vinylester-cplg	Bondstrand 5000M	3	80	45	310	One End	2:50	Pipe developed split adjacent to coupling
15	Steel-flange	Schedule 40	2	50	45	310	One End	27:15	Gasket ruptured in several locations
16	CuNi-brazed cplg	90-10 CuNi	2	50	45	310	One End	30:33*	Steam, then water came from flange joint
17	CuNi-mechanical cplg	90-10 CuNi, Staub metal grip fitting	2	50	45	310	One End	1:30	Gap too large to maintain water pressure
18	Phenolic	Chemtite SP	2	50	45	310	One End	-	Weeped when hydrostatic tested
19	Phenolic-cplg	Chemtite SP	2	50	45	310	One End	6:35	Dripping/pool on floor
20	Phenolic	Chemtite SP	4	100	45	310	One End	-	Weeped when hydrostatic tested
21	Phenolic-cplg	Chemtite SP	4	100	45	310	One End	7:40	Dripping/pool on floor

NOTE: cplg = coupling
* Fuel flow to burner was cut off at 30 minutes.
** Observations during fire test, except as noted.

Total measured heat output was 65 kW (3.5 BTU/sq ft/sec) for all tests.
In all cases, deflection of pipe (measured after the fire) was less than 2.5 percent of the distance between supports.
All test samples failed the post-fire hydrostatic pressure test by not holding pressure.

Couplings in the FGP samples were of the adhesive-bonded sleeve type and were installed by the pipe manufacturers. The steel pipe sample included a bolted flanged coupling. One of the copper-nickel samples had a brazed sleeve-type coupling and the other had a Staub mechanical coupling used in some U.S. Navy shipboard piping systems. Details of the various types of couplings are included in Appendix B.

4.5 Instrumentation

Instrumentation was used to measure ambient conditions, flame temperature, heat flux, propane weight loss, water flow in and out of the test pipe, internal pipe pressure, water temperature inside the pipe and the temperature of the water used for cooling the calorimeters. The calorimeters shown in Figure 4-3 were used only in preliminary calibration tests. A computer-controlled data acquisition system was used to record the test data. Photographic equipment and a video system were used to document the equipment setup, test procedure and results.

4.6 Procedures

Calibrations tests were conducted first and without pipe samples. A steel manifold containing three calorimeters (three inches (76 mm) apart) and three thermocouples (one next to each calorimeter) was used for the calibration tests. The manifold was full of flowing water during calibration testing to cool the calorimeters. The calorimeters measured heat flux at different heights above the tops of the burners while the thermocouples measured air temperatures next to the calorimeters. Flux values were recorded at heights of 62, 125 and 182 mm (2.4, 4.9 and 7.2 inches) above the burners for fuel flows of 2.5 and 5.0 kg/hr (5.5 and 11 lb/hr).

Figure 4-3 shows the positioning of the manifold with reference to the burners. At 1 minute in the calibration tests, the manifold was placed horizontally in Position A for 1 minute, and then shifted to Position B for 1 minute. This was repeated at approximately 13 and 23 minutes in each test. Only one height was checked per test.

For the pipe tests, each sample was tested in a horizontal position, resting on two support mounts as described in Section 4.3. The pipe was 125 mm (4.9 inches) above the burners as specified in the IACS test method. Prior to ignition of the propane burners, an internal pressure was applied by means of the filling and pressurization system.

All pipe tests were scheduled to be 30 minutes in duration. Individual tests were terminated earlier in cases of catastrophic failure of the piping sample (e.g., complete separation at the coupling). Internal pipe pressure was maintained as shown in Table 4-1 for the duration of each test.

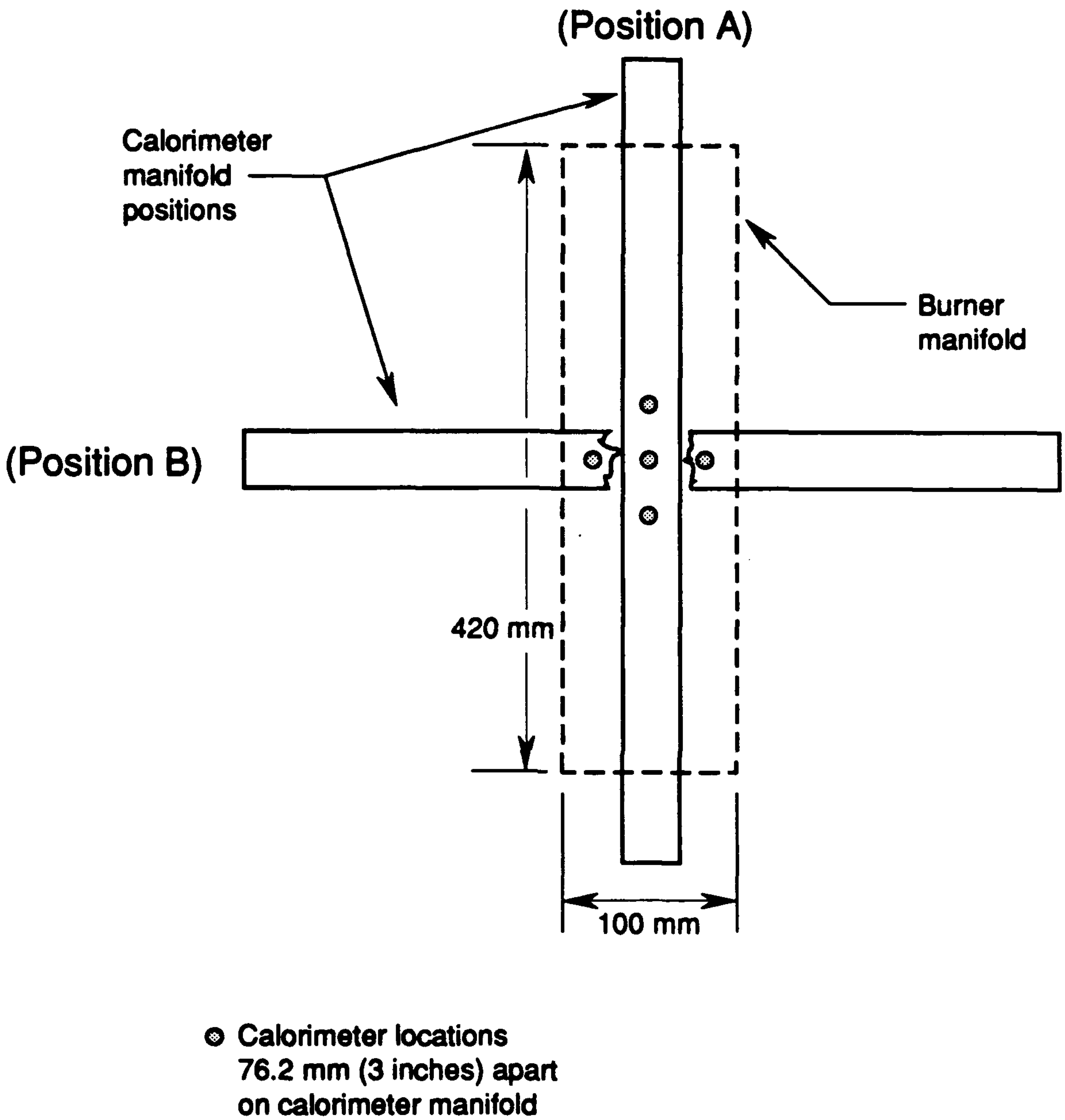


Figure 4-3 Calorimeter Positioning (Calibration Tests)

Burner fuel flow was 5.0 kg/hr (11 lb/hr) for all fire tests. The water leakage rate was measured at the conclusion of each test.

After fire testing, each pipe was allowed to cool to room temperature, and then measured for deflection. Then the sample was hydrostatically tested at 1.5 times the manufacturer's rated pressure of the pipe. This pressure was maintained for 15 minutes and the results were recorded. Leakage observed during all phases of testing was recorded.

4.7 Results

Table 4-1 lists the pipe samples, test parameters and brief comments recorded during testing. Significant observations were as follows:

1. The burner assembly described in the IACS proposal was assembled and setup without any major difficulty. The burner units specified by IACS were readily-available stock items, costing approximately $30 apiece. The air/water pressurization system was relatively easy to construct and operate.

2. The 5 kg/hr (11 lb/hr) propane fuel flow specified in the test procedure produced a theoretical heat output rate of approximately 65 kW (221,800 BTU/hr). Heat flux data obtained at 125 mm (4.9 inches) above the burners during a calibration test with a 5.0 kg/hr (11 lb/hr) fuel flow rate is shown in Figure 4-4.

3. Heat flux measurements recorded at the specified height 125 mm (4.9 in.) to the bottom of the test pipe averaged 9.2 BTU/sq ft/sec (1740 W/m^2) whereas the heat flux at this same height and 102 mm (4 in.) away from a vertical plane through the outer edge of the burners only measured 0.3 BTU/sq ft/sec (57 W/m^2). Consequently, it appears that this specific burner array is not suitable for evaluating pipes larger than 4-inch nominal diameter, unless the number of burner rows (array width) is increased.

4. The heat flux (9.2 BTU/sq ft/sec (1740 W/m^2)) incident on the pipe sample at a height of 125 mm (4.9 in.) was approximately two-thirds the value measured in previous Coast Guard full scale hydrocarbon pool fire pipe testing. Based on this value and the fact that all the piping failed to meet the IACS fire test requirements, it appears that the intensity of the burner fire is too severe for an uninsulated FGP of the types tested.

5. The pipe support arrangement has little effect on pipe performance during fire testing as no difference in

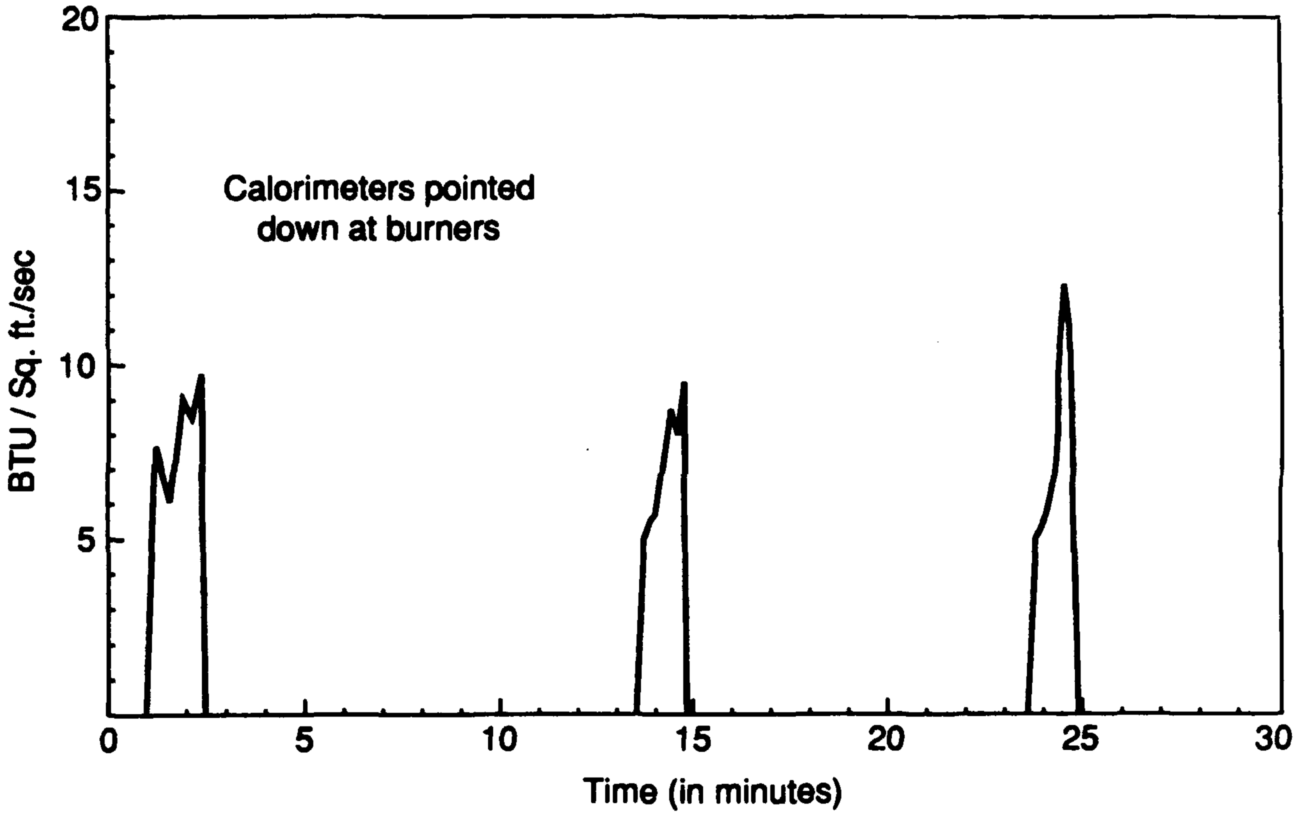


FIGURE 4-4 Burner Test Average Heat Flux at
125 mm (4.9 inches) Above Burners

test results was observed when one pipe support was fixed and the other was free, instead of both supports being fixed.

6. At the beginning of the tests, the internal pipe pressure was either 45 psig or 100 psig (310 kPa or 690 kPa) (See Table 4-1). Pipes with an internal pressure of 100 psig (690 kPa) leaked water sooner in the fire tests than identical pipes with a 45 psig (310 kPa) internal pressure. Water leakage rate from the pipe could not be measured during the fire test but was determined after the test ended.

7. The pipes without couplings leaked but otherwise were not affected by a postfire hydrostatic test of 1.5 times their rated operating pressure. The fiberglass pipes with couplings which did not pop free in the fire test did not separate in the hydrostatic tests.

5.0 PHASE 3 TESTS: Localized Machinery Space Fires

5.1 Phase 3 Objectives

The objectives of this test series were (1) to evaluate the fire endurance of fiberglass piping exposed horizontally and vertically to simulated localized machinery space fires and (2) to compare this data with the results from the IACS Level 3 fire endurance test procedure under consideration by IMO.

5.2 Technical Approach

The most suitable physical arrangement for the simulated localized fires was determined from the provisional fire endurance requirements matrix presented as Annex 2 of Reference 5. This matrix is based on the three levels of fire endurance requirements for plastic piping defined in Reference 2.

For the localized fire case, Fire Endurance Level 3 (the lowest level) and Level 2 (the intermediate level) are applicable. In addition to dry cargo holds and tanks, the matrix includes seven other shipboard location categories. The number of different types of piping systems associated with each of the matrix location categories as follows:

Location Category	Systems with Level 3 Requirements	Systems with Level 2 Requirements
Category A Machinery Spaces	**4**	**1**
Machinery Spaces Other Than Category A	**4**	**1**
Pump Rooms	2	0
Ro/Ro Cargo Holds	1	0
Cofferdams, Void Spaces, Pipe Tunnels and Ducts	0	1
Accommodation, Service and Control Spaces	2	1
Open Decks	3	2

For the purposes of this test series, open decks were eliminated from consideration because of the low frequency of fires originating there. The policy on combustibles in concealed spaces within accommodation, service, and control spaces makes it likely that combustible pipe would be used with a fire protective insulation in those areas. Ro/Ro cargo holds and the cofferdams, etc. categories were not considered because of the small number of piping systems requiring Level 2 or Level 3 fire endurance.

Thus, the most probable situations that would subject piping to fire conditions corresponding to Level 3 or Level 2 requirements would be local fires in machinery spaces. The most common type of fire in these spaces is Class B (liquid fuel).

To conduct the Phase 3 tests, a simulated machinery space compartment (Figure 5-1) was constructed aboard the test vessel MAYO LYKES at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama. The compartment was arranged so that piping could be tested in either a vertical position (to simulate piping running between decks) or a horizontal position (to simulate piping runs in overhead or bilge areas).

The simulated local fires were created by placing a hydrocarbon liquid fuel in a fire pan which could be positioned as desired within the simulated compartment. The pan was sized to produce a fire which could be extinguished by the type of portable extinguisher usually provided for this sort of hazard. The largest portable carbon dioxide extinguisher currently required for fighting Class B fires in machinery spaces contains approximately 15 pounds (6.8 kg) of agent and is capable of extinguishing a 10-square foot (0.9 sq m) fire; thus the size of the test fire pan was 10 square feet (0.9 sq m).

5.3 <u>Test Setup</u>

As shown in Figure 5-1, a simulated machinery space compartment was constructed for these tests on the Second Deck of

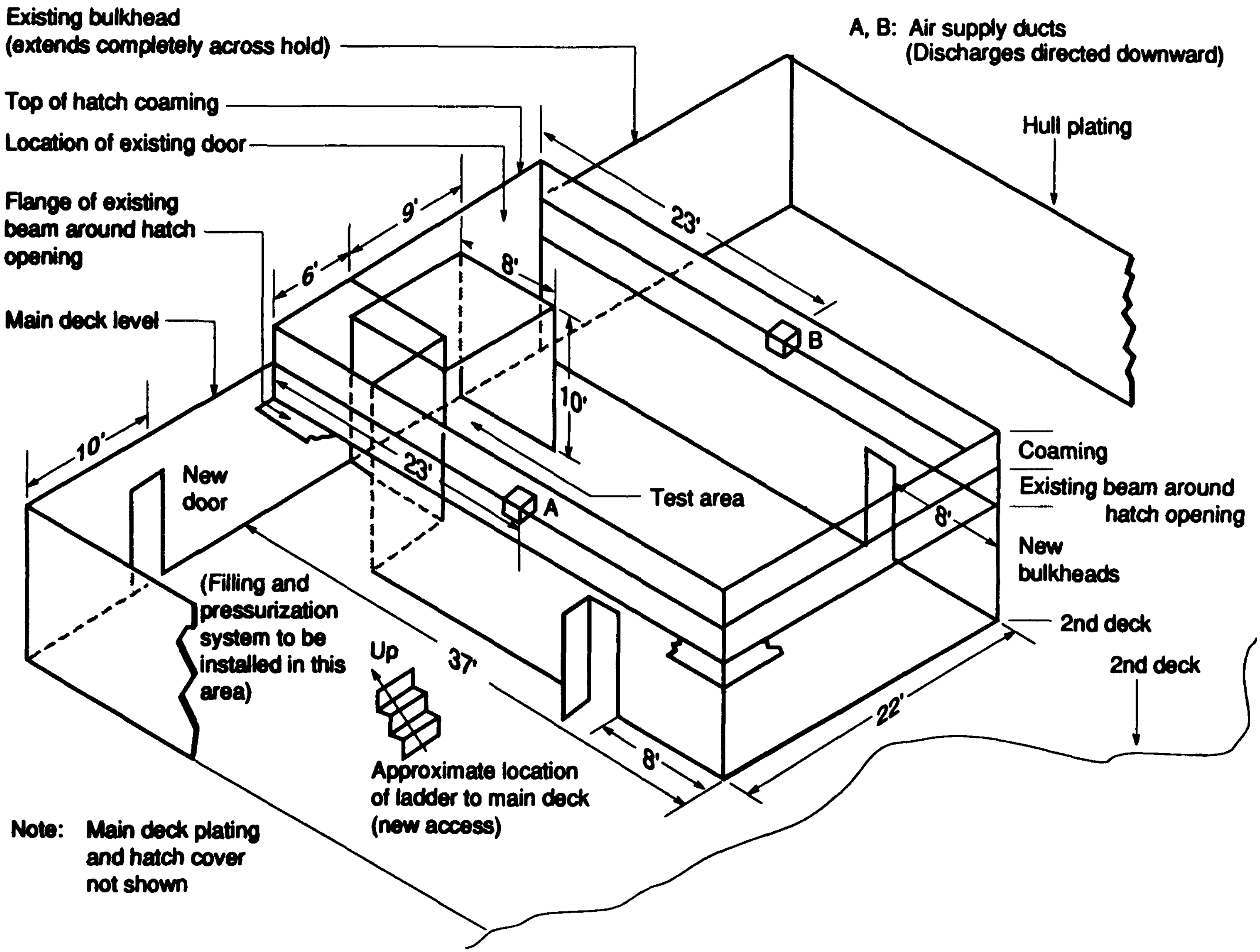


Figure 5-1 Hold No. 3 Arrangement

Hold Number 3 cargo hatch. Approximate overall dimensions of the simulated compartment were 37 feet (11.3 m) long by 22 feet (6.7 m) wide by 13 feet (4.0 m) high. This volume provided sufficient space for conducting the localized test fires.

A partial enclosure, open on the side facing the compartment interior, was constructed at the after end of the simulated compartment. The purpose of the enclosure (identified as the Test Area in Figure 5-1) was to improve repeatability of the test fire conditions by reducing the influence of natural circulation air currents in the vicinity of the test fire pans. The test area enclosure was 8 feet (2.4 m) wide by 9 feet (2.7 m) long by 10 feet (3.0 m) high, and was constructed of sheet steel welded to stiffeners.

Two fans, each rated at 5200 cfm (147 cubic meters per minute) were used to supply ventilation air to the simulated machinery space. These fans were located approximately 23 feet (7.0 m) from the aft bulkhead of the test area. These fans were mounted on the main deck and connected to temporary ducts which discharged directly downward in the test compartment. The ends of the ducts were 8 feet (2.4 m) above the deck. The forward hatch cover above the test compartment was removed to assist the escape of smoke and fire gases from the test area.

The fire pan was 38 inches (970 mm) square and 6 inches (152 mm) deep. A 2-foot (0.6 m) high stand was provided to support the fire pan above the deck for the overhead pipe tests. To contain any fuel spills, a 6-inch (152 mm) high coaming was installed around the test area.

Marine Diesel Fuel was used for all tests. The quantity of fuel required for a test duration of 20 minutes was approximately ten gallons (38 l). To ensure rapid, consistent ignition of the Marine Diesel Fuel, one gallon (3.8 l) of mineral spirits was added to the fire pan just before test fire ignition.

A compressed air/water system (Figure 5-2) was used for pressurizing the test pipes with water during the fire tests. This system was located on the starboard side of Hold Number 3. A separate arrangement including a test pump was used for hydrostatically testing the pipes following fire exposure.

5.4 Test specimens

Each pipe sample was 138 inches (3.5 m) long. In most cases, the sample was a single length of pipe with flanges at both ends. Table 5-1 list the pipes used in each test. Samples that were tested full of stagnant water were fitted with a blank flange at one end and connected to the air/water pressurization system at the other end.

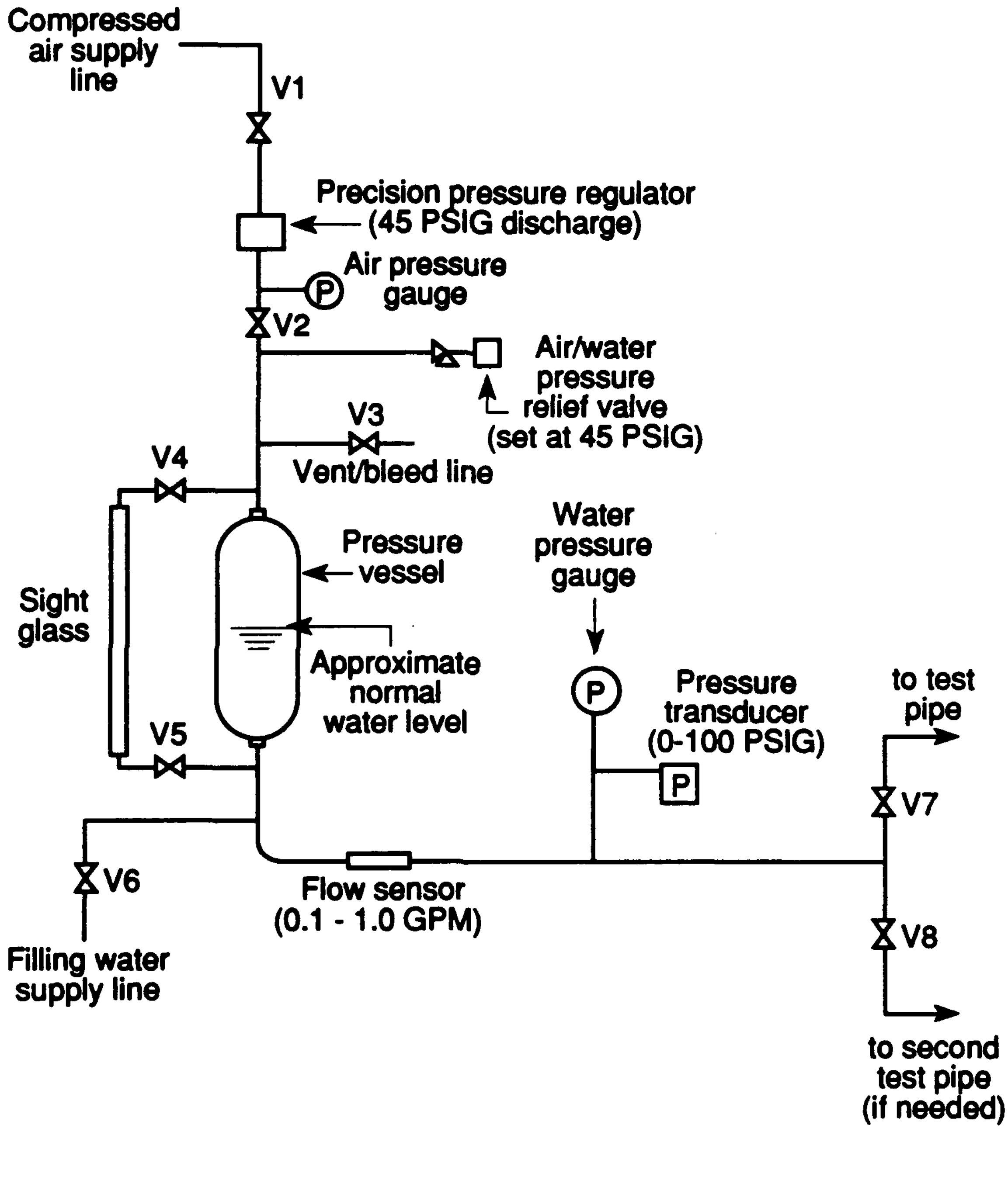


Figure 5-2 Schematic of Air / Water System

TABLE 5-1 Results of Localized Machinery Space Fire Tests on Pipes

Test No.	Pipe Description	Manufacturer's Description	Nominal Pipe Size (inches)	Nominal Pipe Size (mm)	Configuration Simulated In Test Vertical, Overhead or Bilge	Test Conditions Wet	Test Conditions Dry	Pipes Tested	Test Results Char Length (feet)	Test Results Char Length (meters)	Test Results Hydro Test Results (F = Failed) (P = Passed)
1	FGP-Phenolic	Chemtite SP	2	50	Vertical		Dry	2	9.5, 9.5	2.4, 2.4	F, F
2	FGP-Epoxy	Green Thread	6	150	Vertical		Dry	2	10, 10	2.5, 2.5	F, F
3	FGP-Epoxy	Green Thread	3	80	Vertical		Dry	2	10, 10	2.5, 2.5	F, F
4	FGP-Epoxy	Green Thread	2	50	Vertical		Dry	1	10	2.5	F
5	FGP-Vinylester	Poly Thread	4	100	Vertical		Dry	1	9.5	2.4	F
6	FGP-Epoxy	Bondstrand 2000M	2	50	Vertical	Wet		2	6, 5	1.5, 1.3	F, F
7	FGP-Epoxy	Bondstrand 2000M	3	80	Vertical		Dry	2	10, 10	2.5, 2.5	F
8	FGP-Phenolic (cplg)	Chemtite SP	4	100	Vertical	Wet		2	5, 5	1.3, 1.3	P, P
9	FGP-Phenolic	Chemtite SP	4	100	Overhead	Wet		1	discolored		P
10	FGP-Phenolic	Chemtite SP	4	100	Overhead		Dry	1	8	2.0	F
11	FGP-Epoxy	Green Thread	4	100	Overhead	Wet		1	discolored		P
12	FGP-Epoxy	Green Thread	2	50	Overhead		Dry	1	9	2.3	F
13	FGP-Epoxy (cplg)	Green Thread	2	50	Overhead		Dry	2	8.5, 8.5	2.2, 2.2	F, F
14	FGP-Vinylester	Poly Thread	2	50	Overhead		Dry	1	8.5	2.2	F
15	FGP-Vinylester	Poly Thread	2	50	Overhead	Wet		1	discolored		P
16	FGP-Epoxy	Bondstrand 2000M	2	50	Overhead	Wet		1	discolored		P
17	FGP-Epoxy	Bondstrand 2000M	2	50	Overhead		Dry	1	9	2.3	F
18	FGP-Vinylester	Bondstrand 5000M	6	150	Overhead	Wet		1	discolored		P
19	FGP-Vinylester	Bondstrand 5000M	6	150	Overhead		Dry	1	9	2.3	F
20	PVC	Type I	4	100	Overhead	Wet		1	7.5	1.9	F
21	PVC	Type I	4	100	Overhead		Dry	1	destroyed		-
22	FGP-Phenolic	Chemtite SP	6	150	Bilge	Wet		1	6	1.5	P
23	FGP-Phenolic	Chemtite SP	6	150	Bilge		Dry	1	7	1.8	F
24	FGP-Epoxy	Green Thread	4	100	Bilge	Wet		1	7	1.8	F
25	FGP-Epoxy	Green Thread	4	100	Bilge		Dry	1	8	2.0	F
26	FGP-Vinylester (cplg)	Poly Thread	2	50	Bilge	Wet		1	separated	at cplg	-
27	FGP-Vinylester	Poly Thread	2	50	Bilge		Dry	1	8	2.0	F
28	FGP-Epoxy	Bondstrand 2000M	2	50	Bilge	Wet		1	8	2.0	F
29	FGP-Epoxy (cplg)	Bondstrand 2000M	2	50	Bilge		Dry	1	8	2.0	F
30	FGP-Epoxy	Bondstrand 2000M	6	150	Bilge		Dry	1	8	2.0	F
31	FGP-Epoxy	Bondstrand 2000M	6	150	Bilge	Wet		1	6	1.5	F
32	FGP-Vinylester	Bondstrand 5000M	2	50	Bilge	Wet		1	6	1.5	F
33	FGP-Vinylester	Bondstrand 5000M	2	50	Bilge		Dry	1	8	2.0	F
34	PVC	Type I	4	100	Bilge	Wet		1	8	2.0	F
35	PVC	Type I	4	100	Bilge		Dry	1	destroyed		-
36	FGP-Epoxy	Green Thread	2	50	Vertical		Dry	2*	5, discolored	1.3, -	F, P
37	PVC	Type I	4	100	Vertical		Dry	2*	both collapsed		-
38	FGP-Vinylester	Poly Thread	6	150	Vertical		Dry	2*	6, discolored	1.5, -	F, P
39	FGP-Epoxy	Green Thread	2	50	Overhead		Dry	2*	8, discolored	2.0, -	F, P
40	PVC	Type I	4	100	Overhead		Dry	2*	both collapsed		-
41	FGP-Vinylester	Bondstrand 5000M	4	100	Overhead		Dry	2*	9, discolored	2.3 -	P, P

* First pipe 18 inches (457 mm) from pan, 2nd pipe 36 inches (914 mm) from pan.
cplg = coupling

Four different piping materials were included in the Phase 3 tests:

Fiberglass reinforced epoxy pipe
(Ameron Bondstrand 2000M and
Smith Green Thread)

Fiberglass reinforced vinylester pipe
(Ameron Bondstrand 5000M and
Smith Poly Thread)

Fiberglass reinforced phenolic pipe
(Ametek Haveg SP)

Polyvinyl chloride pipe
(Charlotte Plastics Type I PVC)

Additional descriptions and dimensional data for each of these varieties are included in Appendix C.

5.5 Instrumentation

Instrumentation was used to measure ambient conditions, flame temperature, heat flux, temperature inside the test area, internal pipe pressure, water temperature inside the pipes and temperature of the water cooling the calorimeters. A computer data acquisition system was used to record the test data.

Video cameras and photographic equipment were used to document the equipment setup, test procedures and results. One video camera was positioned on the deck of the simulated machinery space and directed towards the test area. This camera was protected from the smoke and heat. A second video camera viewing the test area was positioned in the alcove to starboard of the test area. The two video cameras were connected to a single recorder so that either view could be recorded. A time/date generator was used with this video system. A portable camcorder was used to record general test setup and instrumentation.

5.6 Procedures

Baseline Tests

Baseline fire tests were conducted without pipes to determine the quantity of fuel required for a 20-minute fire. Previous tests indicate that Marine Diesel burns at a rate of about 0.2 inch (5 mm) of depth per minute. The baseline tests provided information on temperature and heat flux profiles in the absence of the test pipes. Profiles of these same parameters were also collected during the pipe tests.

Test Pipe Arrangements

Pipes were tested one, two, or three at a time in vertical, overhead and bilge configurations (see Table 5-1). Figures 5-3 through 5-8 show the location of the pipes for each configuration. The pipes were either dry or pressurized with stagnant water.

Vertical Pipe Tests

The fire pan was positioned on the centerline of the test area, 6 inches (152 mm) from the aft bulkhead (see Figures 5-3 and 5-4). A single pipe was placed on the centerline and 1 foot (0.3 m) from the aft bulkhead. A second pipe was placed two inches (51 mm) to starboard of the first pipe. The lower ends of the pipes rested in 6-inch (152 mm) high steel cups setting in the fire pan. Each pipe extended through the top of the test area and was clamped in place. Insulation was used to seal around the pipe where it passed through the top of the test area. The dry pipes were open at the top, while the upper ends of the pipes containing pressurized stagnant water were connected to the air/water system shown in Figure 5-2.

Four vertical tests involved three pipes in a dry condition. The pipes were located 1 foot (0.3 m) from the aft bulkhead and spaced to port at 1-foot (0.3 m) intervals starting on the centerline.

Overhead Pipe Tests

Each pipe extended through the port/starboard bulkheads, 1 foot (0.3 m) beneath the overhead of the test area (see Figures 5-5 and 5-6). When a single pipe was tested, it was positioned 4 feet (1.2 m) from the aft bulkhead. A second pipe, when tested, was positioned 2 inches (51 mm) forward of the single pipe. For tests using pressurized stagnant water, the port end of the pipe sample was blanked off and the starboard end was attached to the air/water system shown in Figure 5-2. For dry tests, the port end was open and the starboard end was closed with insulation.

Four overhead tests involved three dry pipes per test. The pipes were located at 1.5-foot (0.5 m) intervals forward of the centerline of the test area's port and starboard bulkheads. The pipes were 1 foot (0.3 m) below the overhead in the test area.

Bilge Pipe Tests

A 4 foot (1.2 m) by 8 foot (2.4 m) steel plate (simulating a solid bilge plate) was placed on a stand 4 feet above the deck in the test area. The plate and stand were positioned athwartships and centered in the test area. The fire pan was located on the deck, under the bilge plate and centered between the port and starboard bulkheads.

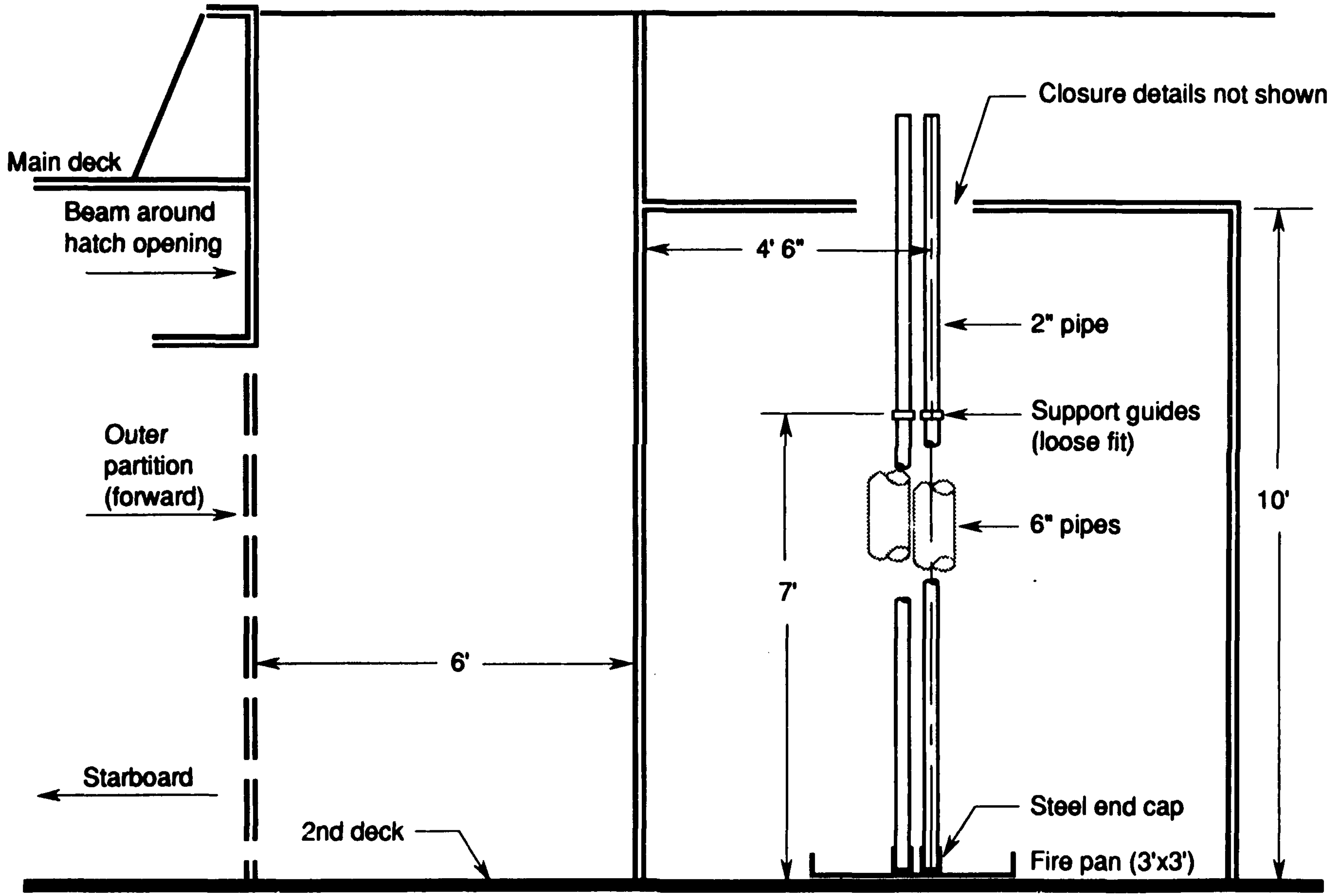


Figure 5-3 Elevation View of Test Area, Looking Aft (Vertical Pipe Tests)

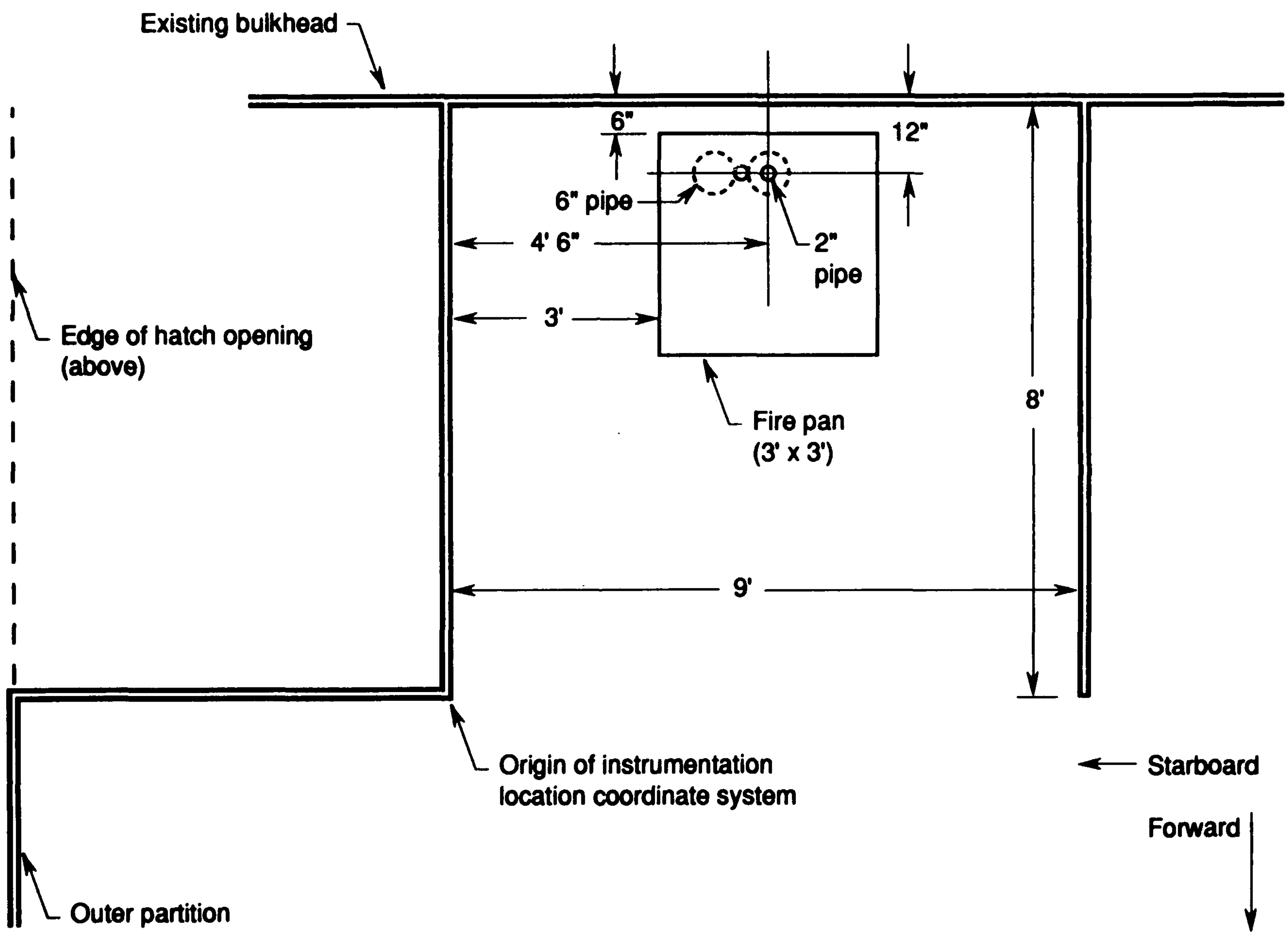


Figure 5-4 Plan View of Test Area (Vertical Pipe Tests)

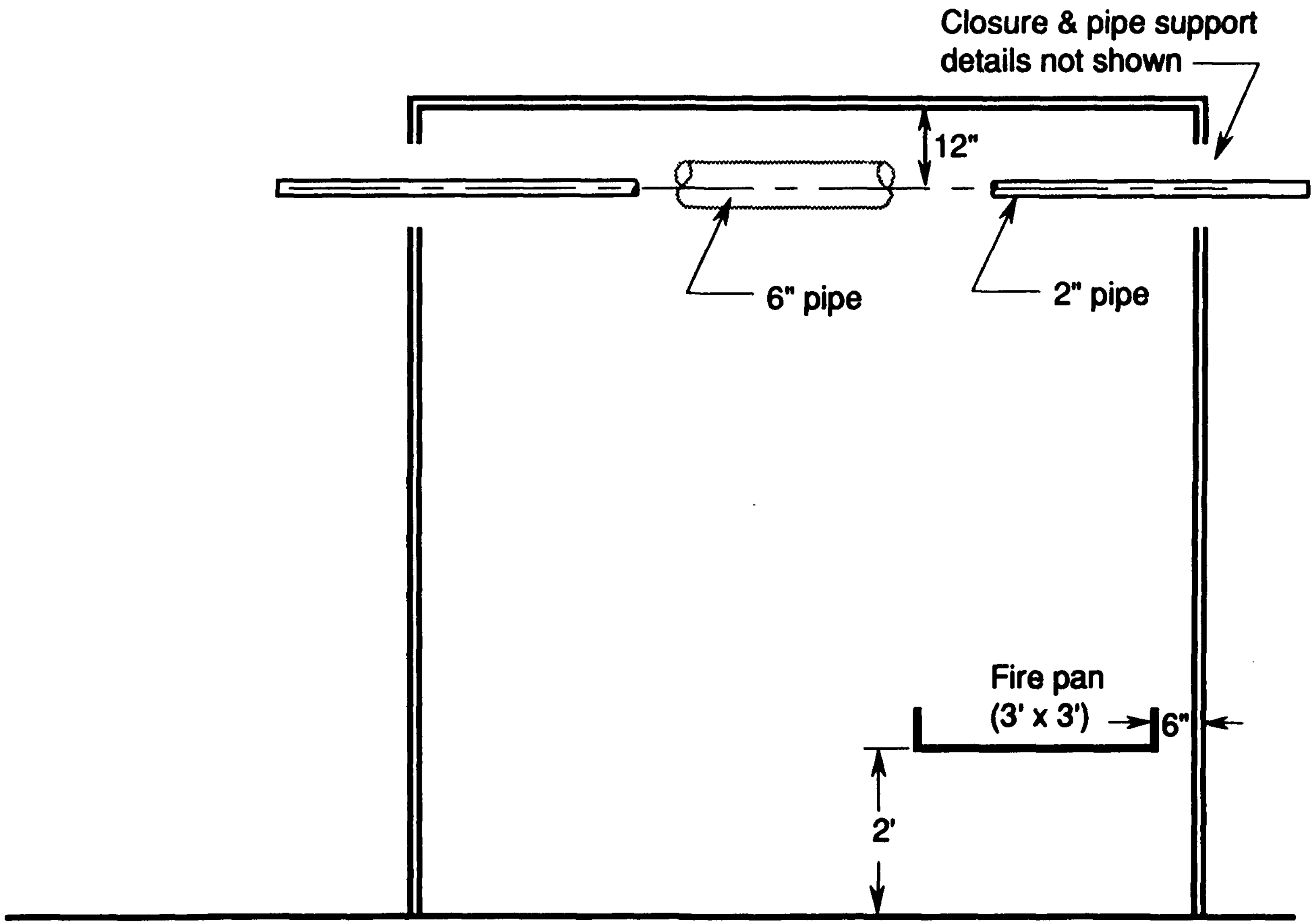


Figure 5-5 Elevation View of Test Area, Looking Aft (Overhead Pipe Tests)

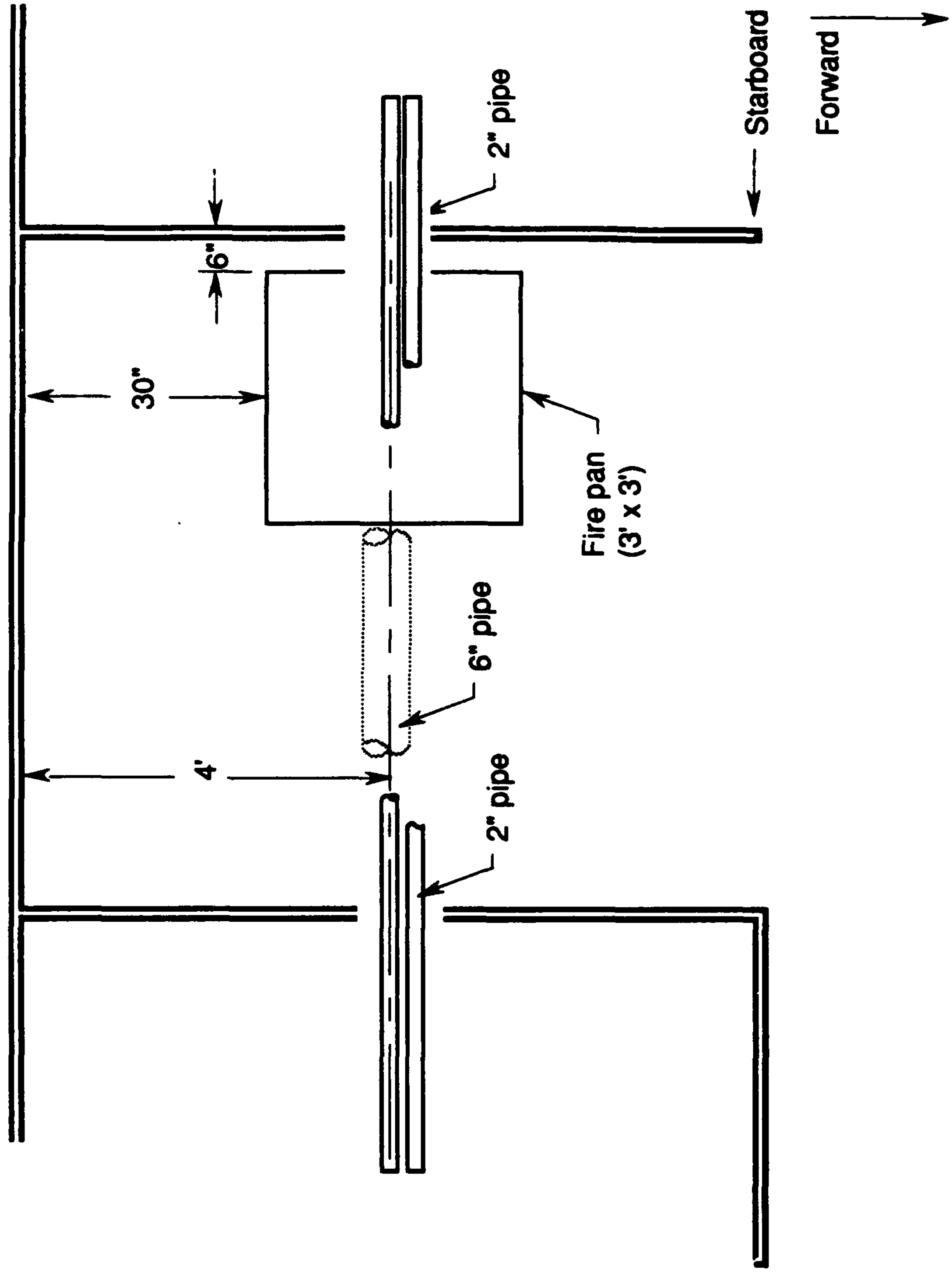


Figure 5-6 Plan View of Test Area (Overhead Pipe Tests)

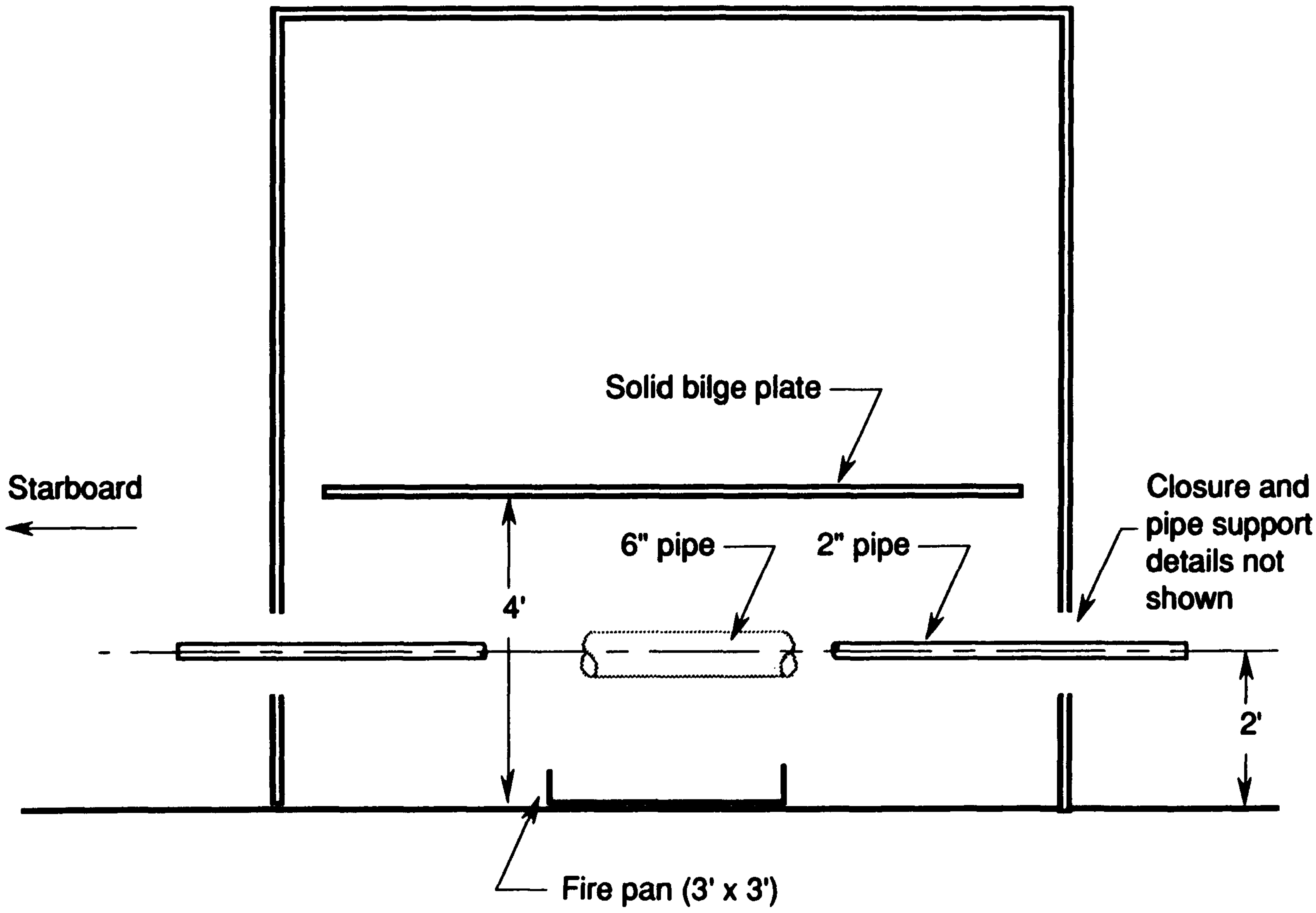


Figure 5-7 Elevation View of Test Area, Looking Aft (Bilge Pipe Tests)

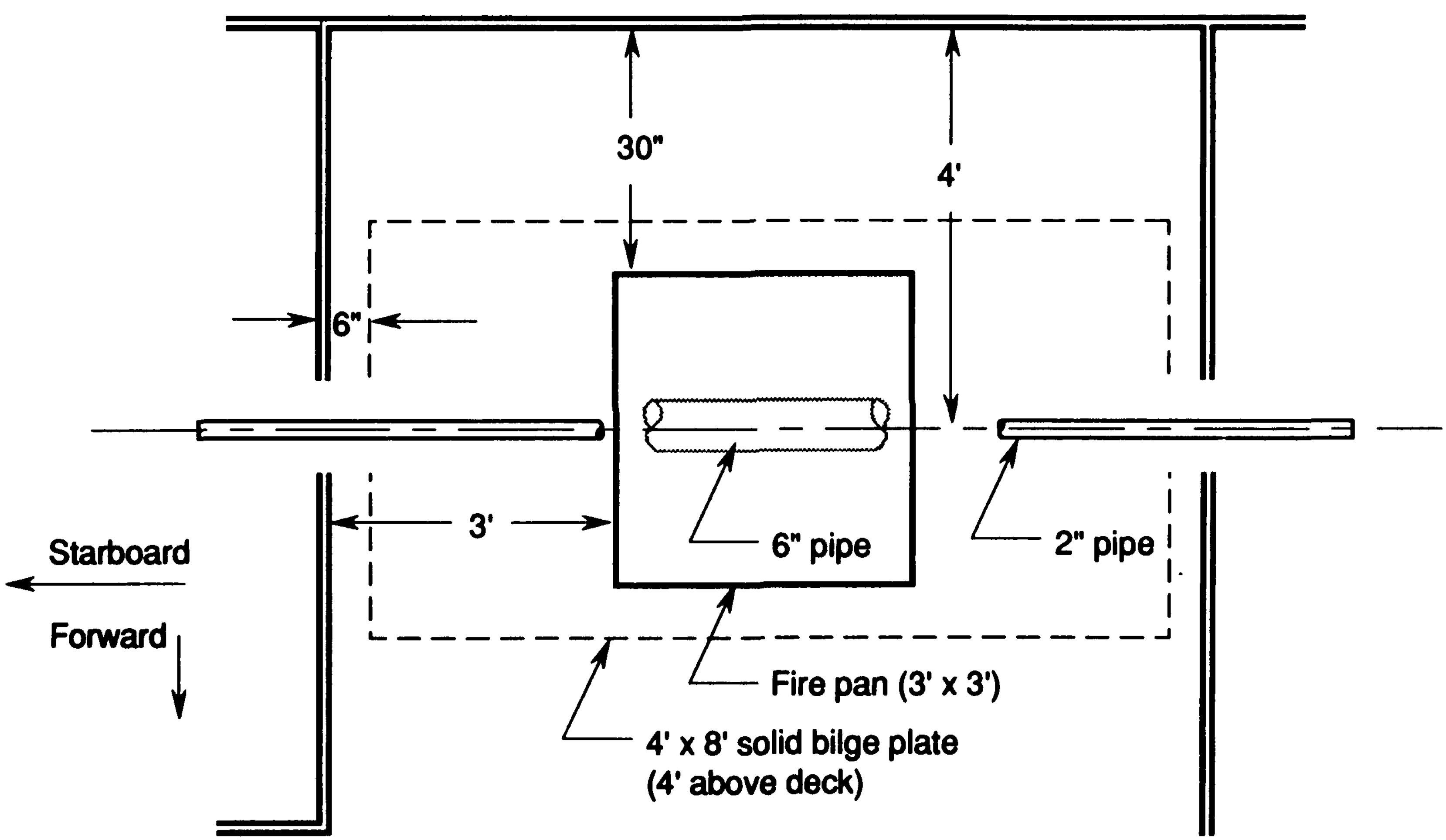


Figure 5-8 Plan View of Test Area (Bilge Pipe Tests)

Each test pipe was located 4 feet (1.2 m) from the aft bulkhead, 2 feet (0.6 m) above the deck and extended through the port and starboard bulkheads (see Figures 5-7 and 5-8). Thus, the test pipe was 2 feet (0.6 m) below the bilge plate. For pressurized stagnant water tests, the port end of the pipe was secured with a coupling and length of closed pipe, and the starboard end was attached to the air/water system shown in Figure 5-2. For dry tests, the port end of the pipe was open and the starboard end was closed with insulation.

Hydrostatic Pressure Tests

Pipe samples were hydrostatically pressure tested at the conclusion of fire testing. Those samples which leaked water during fire testing were omitted from the hydrostatic test.

5.7 Results

Table 5-1 provides the general results of each test with regard to charring, water leakage during fire testing and whether the samples passed the hydrostatic test. A summary of the observations recorded during testing follows:

a. PVC pipes melted, burned, and collapsed in all dry tests. They melted, sagged and leaked water in all wet tests.

b. Dry 2- to 6-inch diameter epoxy, vinylester and phenolic fiberglass pipes in direct flame contact burned, charred, and subsequently failed hydrostatic testing. The epoxy and vinylester pipes also lost structural rigidity.

c. Wet 4- to 6-inch diameter phenolic fiberglass pipe charred in direct flame contact, but passed hydrostatic testing.

d. Wet 2- to 6-inch epoxy and vinylester fiberglass pipe burned, charred and did not pass hydrostatic testing.

e. Fiberglass and PVC pipe integrity (ability to hold pressure) can be lost without visible signs of resin burning or of direct flame contact to the pipes.

f. The glue in the quick-connect coupling of the wet vinylester (Poly Thread) pipe melted in direct flame contact and permitted pipe separation.

6.0 SUMMARY AND CONCLUSIONS

6.1 Summary

Fire endurance testing of FGP at the U.S. Coast Guard's Fire and Safety Test Detachment was conducted using three types of fire exposure tests:

(a) Large hydrocarbon liquid pool fire tests
(b) IACS propane burner assembly tests
(c) Localized machinery space fire tests

In some tests, FGP was compared directly with metallic piping materials (i.e., carbon steel and 90-10 copper nickel) as well as with non-reinforced plastic piping (i.e., PVC).

Test specimens included a variety of pipe connections and fittings along with straight sections of pipe.

Key data obtained during the tests included temperatures and heat flux profiles.

6.2 Conclusions

A. Phase 1 - Large hydrocarbon liquid pool fire tests

1. FGP can survive a large pool fire if it contains flowing water during the fire; however, appreciable leakage may be expected at the joints. If the FGP is dry, or contains stagnant water, the pipe will lose its structural integrity shortly after the fire starts. (This occurred within 3 to 6 minutes during the Phase 1 tests.)

2. Joints are the weakest link in an FGP system.

3. Steel pipes will remain intact throughout a fire of this severity, but a significant amount of leakage can occur if the joint seals are damaged by the fire.

4. Large hydrocarbon pool fires conducted outdoors are easily affected by wind conditions. Therefore, this type of test is not recommended as a standard test method because of insufficient repeatability of fire parameters.

B. Phase 2 - IACS propane burner assembly tests

1. The test apparatus proposed by IACS can be set up and operated fairly easily.

2. The 5 kg/hr (11 lb/hr) propane flow rate specified by IACS theoretically will produce a heat output rate of approximately 65 kW (221,800 BTU/hr).

3. The propane burner configuration specified in the proposed IACS test method is applicable for pipes up to 4-inch (102 mm) nominal size. The outside diameter of 4-inch (102 mm) pipe is about the same as the width of the specified burner array. For larger pipes, the number of burner rows needs to be increased by one row per each 2-inch (51 mm) increase in pipe diameter, and the same heat flux would have to be maintained.

4. For the proposed IACS test method, the pipe specimen support conditions can be either fixed-free or fixed-fixed without significantly affecting results.

5. During fire tests, leakage and/or catastrophic failure of the test pipes could be observed visually; however, it was not possible to accurately measure the leakage rates with the instrumentation installed in the filling/pressurization system.

6. At the specified height of 125 mm (4.9 inches) above the burners, an incident heat flux of approximately 9.2 BTU/sq ft/sec (1740 W/m^2) is produced. This value is about two-thirds of that measured during the Phase 1 tests.

7. Because of the relatively high observed heat flux and the fact that all of the test specimens (metal as well as FGP) failed to meet the IACS leakage or post-fire hydrostatic pressure test, it can be concluded that the intensity of the fire exposure produced by this test method is too severe for uninsulated FGP of the types tested. Pipe deflections were within IACS limits.

8. An explosion hazard exists when sealed pipe samples are exposed to fire. If the pressure relief device fails or has inadequate capacity, the pipe may burst violently. Testing laboratories should be aware of the hazards associated with this type of test and the extensive safety precautions that are necessary to protect personnel and laboratory equipment.

C. Phase 3 - Localized machinery space fire tests

1. Dry epoxy, vinylester, and phenolic FGP will char and burn during a fire and thus fail a hydrostatic pressure test. Dry epoxy and vinylester pipe will also lose structural rigidity during a fire.

2. Water-filled phenolic FGP will char during a fire, but will pass a hydrostatic pressure test. Water-filled epoxy and vinylester FGP will char and burn in a fire, and also fail a hydrostatic pressure test.

3. Water-filled PVC pipes will melt, sag and leak during a fire.

4. Structural integrity (as determined by the hydrostatic test) can be lost by dry FGP and dry PVC pipe even when there is no visible indication of burning resin or direct flame contact.

5. The adhesive used in connecting quick-connect couplings for epoxy and vinylester pipes will deteriorate when exposed to flames, thus allowing the joint to separate and the pipe system to lose its structural integrity.

As each phase of these tests was completed, the test summaries were used in developing Coast Guard recommendations regarding acceptance criteria for fiberglass reinforced plastic pipe materials. These recommendations were periodically submitted to the IMO Working Group on Materials Other Than Steel for Pipes of the Sub-Committee on Fire Protection. The Working Group has been directed to finalize the fire protection requirements for both plastic and reinforced plastic piping, based on information submitted by the United Sates and other IMO-member countries. The Sub-Committee has issued a document titled Draft Guidelines for Selection of Plastic Materials for Pipes, part of IMO document FP 35/WP.9, dated 5 July 1990.

REFERENCES

1. Navigation and Vessel Inspection Circular No. 11-86, Enclosure (1), Guidelines Governing the Use of Fiberglass Pipe (FGP) on Coast Guard Inspected Vessels. Department of Transportation, U.S. Coast Guard, 5 September 1986.

2. Submittal by the International Association of Classification Societies (IACS) to the International Maritime Organization (IMO) Sub-Committee on Fire Protection - 33rd Session (IMO document FP 33/11/4, dated 17 December 1987).

3. Proposed Test Methods for Determining Effects of Large Hydrocarbon Pool Fires on Structural Members and Assemblies (ASTM P-191). American Society for Testing and Materials, E5.11 Task Group 3, November, 1988.

4. International Convention for the Safety of Life at Sea (Consolidated Text of the 1974 SOLAS Convention, the 1978 SOLAS Protocol and the 1981 and 1983 SOLAS Amendments). International Maritime Organization, London, 1986.

5. Report of the Working Group on Materials Other Than Steel for Pipes; IMO Sub-Committee on Fire Protection, 34th session (IMO document FP 34/9, dated 10 May 1988).

APPENDIX A

Description of Phase 1 Piping Test Specimens

Materials

All of the nonmetallic pipe used in the Phase 1 tests were reinforced thermosetting resin pipe which the American Society for Testing and Materials designates as RTRP. All of the RTRP used in these tests were manufactured by the filament winding process. Details for the individual varieties of nonmetallic pipe are as follows:

Ameron Bondstrand 2000M:
Fiberglass reinforced epoxy pipe with 0.02-inch (0.5 mm) thick integral resin-rich epoxy liner.

Ameron Bondstrand 7000M:
Fiberglass reinforced epoxy resin pipe with integrally wound electrically conductive filaments in pipe wall.

One type of metallic pipe was used in the tests:

Carbon steel
ASTM A53 Grade B (Schedule 40 pipe).

Flanges and Fittings

The different flanges and fittings incorporated into the test specimens are shown in Figures 3-2 and 3-3. The FGP piping, flanges, and fittings were Ameron Bondstrand 7000M (Tests 1 and 2) and 2000M (Tests 3 and 4).

Dimensions

The dimensions of the pipes are given in Table A-1.

TABLE A-1. Description of Phase 1 Piping Test Specimens

Pipe Dimensions

The following dimensions were obtained from manufacturers' product data sheets and design manuals:

Type and Nominal Size		Outside Diameter	Inside Diameter	Wall Thickness
FGP (Epoxy 7000M)	10"	10.99" (279.1 mm)	10.35" (262.9 mm)	0.32" (8.1 mm)
FGP (Epoxy 2000M)	8"	8.76" (222.8 mm)	8.22" (208.8 mm)	0.27" (7.0 mm)
Carbon Steel (Sch 40)	2"	2.38" (60.3 mm)	2.07" (53.5 mm)	0.154" (3.9 mm)
	10"	10.75" (273.0 mm)	10.02" (254.5 mm)	0.365" (9.2 mm)
	8"	8.63" (219.1 mm)	7.98" (202.7 mm)	0.322" (8.2 mm)

APPENDIX B

Description of Phase 2 Piping Test Specimens

Materials

All of the nonmetallic pipe used in the Phase 2 tests were reinforced thermosetting resin pipe which the American Society for Testing and Materials designates as RTRP. All the RTRP in these tests were manufactured by the filament winding process. Details for the individual varieties of nonmetallic pipe are as follows:

Ameron Bondstrand 2000M:
Fiberglass reinforced epoxy pipe with 0.02-inch (0.5 mm) thick integral resin-rich epoxy liner.

Ameron Bondstrand 5000M:
Fiberglass reinforced vinylester pipe with integral 0.05-inch (1.3 mm) thick resin rich reinforced liner and 0.25-inch (6 mm) closed-cell foam external coating. (The ASTM designation for this pipe is RTRP 12ED-1012; see ASTM Standard D2996.)

Ametek Haveg SP
Pipe consisting of silica filaments and fillers with a phenolic resin binder.

Smith Green Thread
Fiberglass reinforced epoxy resin pipe with glass mat reinforced epoxy resin-rich liner. Nominal liner thickness is 0.03 inch (0.8 mm) for pipe sizes larger than 2 inches, and 0.015 inch (0.4 mm) for smaller sizes. (The ASTM designation for this pipe is RTRP-11FF; see ASTM Standard D2310.)

Smith Poly Thread
Fiberglass reinforced vinylester resin pipe with a 0.03 inch (0.8 mm) thick glass mat reinforced vinylester resin liner. (The ASTM designation for this pipe is RTRP-12EF; see ASTM Standard D2310.)

Two types of metallic materials were included in the tests:

Carbon steel
ASTM A53 Grade B (Schedule 40 pipe).

90-10 Copper nickel alloy
MIL-T-16420 class 200 tubing. (Chemical and mechanical property requirements for this Military Specification are similar to the requirements of copper alloy number 706 of ASTM Standard B466.)

Description of Phase 2 Piping Test Specimens (continued)

Pipe Couplings

Where couplings were used on the FGP samples, they were the unthreaded, adhesive-bonded sleeve type. Manufacturers' descriptions were as follows:

Ameron Bondstrand 2000M and 5000M:
Quick-Lock couplings

Smith Green Thread and Poly Thread:
Sleeve couplings

Haveg Chemtite SP:
Coupling

Charlotte Plastics PVC:
Coupling, socket x socket

The steel pipe sample was fitted with a bolted flange coupling. A 1/8-inch (3.2 mm) thick marine gasket composed of 80 percent chrysotile asbestos encapsulated in synthetic rubber was installed between the flanges.

One of the copper-nickel samples included a 4-inch (102 mm) long silver-brazed sleeve coupling. The second sample included a Staub metal grip fitting, a type of mechanical pipe coupling with internal O-ring seals which is used on some U.S. Navy shipboard piping systems.

Dimensions

The dimensions of the pipes are given in Table B-1.

TABLE B-1. Description of Phase 2 Piping Test Specimens

Pipe Dimensions

The following dimensions were obtained from manufacturers' product data sheets and design manuals:

Type and Nominal Size		Outside Diameter		Inside Diameter		Wall Thickness	
FGP (Epoxy 2000M)	2"	2.38"	(60.3 mm)	2.09"	(53.1 mm)	0.140"	(3.6 mm)
FGP (Epoxy 2000M)	4"	4.50"	(114.3 mm)	4.14"	(105.2 mm)	0.180"	(4.6 mm)
FGP (Vinylester 5000M)	3"	3.53"	(89.7 mm)[1]	3.22"	(81.8 mm)	0.157"	(4.0 mm)
FGP (Phenolic)	2"	2.38"	(60.3 mm)	2.01"	(51.1 mm)	0.18"	(4.6 mm)
FGP (Phenolic)	4"	4.50"	(114.3 mm)	3.99"	(101.3 mm)	0.25"	(6.4 mm)
FGP (Epoxy-Green Thread)	1"	1.34"	(33.9 mm)	1.19"	(30.2 mm)	0.073"	(1.9 mm)[2]
FGP (Epoxy-Green Thread)	2"	2.38"	(60.3 mm)	2.15"	(54.5 mm)	0.115"	(2.9 mm)
FGP (Epoxy-Green Thread)	4"	4.50"	(114.3 mm)	4.27"	(108.5 mm)	0.115"	(2.9 mm)
FGP (Vinylester-Poly Thread)	2"	2.38"	(60.3 mm)	2.14"	(54.2 mm)	0.120"	(3.0 mm)
Carbon Steel (Sch 40)	2"	2.38"	(60.3 mm)	2.07"	(53.5 mm)	0.154"	(3.9 mm)
90-10 Copper-Nickel	2"	2.38"	(60.3 mm)	2.21"	(56.1 mm)	0.083"	(2.1 mm)

NOTE 1: Not including 0.25" (6.4 mm) protective foam coating.
2: Total including 15 mm (0.6 inches) liner.

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APPENDIX C

Description of Phase 3 Piping Test Specimens

Materials

All of the fiberglass reinforced pipe used in the Phase 3 tests were reinforced thermosetting resin pipe (which the American Society for Testing and Materials designates as RTRP). All the RTRP used in these tests were manufactured by the filament winding process. Details for the individual varieties of pipe are as follows:

Ameron Bondstrand 2000M:
Fiberglass reinforced epoxy pipe with 0.02-inch (0.5 mm) thick integral resin-rich epoxy liner.

Ameron Bondstrand 5000M:
Fiberglass reinforced vinylester pipe with integral 0.05-inch (1.3 mm) thick resin rich reinforced liner and 0.25-inch (6 mm) closed-cell foam external coating. (The ASTM designation for this pipe is RTRP 12ED-1012; see ASTM Standard D2996.)

Ametek Haveg SP
Pipe consisting of silica filaments and fillers with a phenolic resin binder.

Smith Green Thread
Fiberglass reinforced epoxy resin pipe with glass mat reinforced epoxy resin-rich liner. Nominal liner thickness is 0.030 inch (0.8 mm) for pipe sizes larger than 2 inches, and 0.015 inch (0.4 mm) for smaller sizes. (The ASTM designation for this pipe is RTRP-11FF; see ASTM Standard D2310.)

Smith Poly Thread
Fiberglass reinforced vinylester resin pipe with a 0.030 inch (0.8 mm) thick glass mat reinforced vinylester resin liner. (The ASTM designation for this pipe is RTRP-12EF; see ASTM Standard D2310.)

Dimensions

The dimensions of the pipes are given in Table C-1.

TABLE C-1. Description of Phase 3 Piping Test Specimens

Pipe Dimensions

The following dimensions were obtained from manufacturers' product data sheets and design manuals:

Type and Nominal Size		Outside Diameter	Inside Diameter	Wall Thickness
FGP (Phenolic)	2"	2.38" (60.3 mm)	2.01" (51.1 mm)	0.18" (4.6mm)
FGP (Phenolic)	4"	4.50" (114.3 mm)	3.99" (101.3 mm)	
FGP (Phenolic)	6"			
FGP (Epoxy-Green Thread)	2"	2.38" (60.3 mm)	2.15" (54.5 mm)	0.115" (2.9 mm)[2]
FGP (Epoxy-Green Thread)	3"	3.50" (88.9 mm)	3.27" (83.1 mm)	0.115" (2.9 mm)[2]
FGP (Epoxy-Green Thread)	4"	4.50" (114.3 mm)	4.27" (108.5 mm)	0.115" (2.9 mm)[2]
FGP (Epoxy-Green Thread)	6"	6.63" (168.3 mm)	6.34" (160.9 mm)	0.145" (3.7 mm)[2]
FGP (Epoxy 2000M)	2"	2.38" (60.3 mm)	2.09" (53.1 mm)	0.140" (3.6 mm)
FGP (Epoxy 2000M)	3"	3.50" (88.9 mm)	3.22" (81.8 mm)	0.140" (3.6 mm)
FGP (Epoxy 2000M)	6"	6.64" (168.6 mm)	6.26" (159.0 mm)	0.188" (4.8 mm)
FGP (Vinylester 5000M)	2"	2.42" (61.5 mm)[1]	2.10" (53.3 mm)	0.157" (4.0 mm)
FGP (Vinylester 5000M)	4"	4.54" (115.3 mm)[1]	4.14" (105.2 mm)	0.157" (4.0 mm)
FGP (Vinylester 5000M)	6"	6.67" (169.4 mm)[1]	6.26" (159.0 mm)	0.203" (5.2 mm)
FGP (Vinylester-Poly Thread)	2"	2.38" (60.3 mm)	2.14" (54.2 mm)	0.120" (3.0 mm)
FGP (Vinylester-Poly Thread)	4"	4.50" (114.3 mm)	4.26" (108.2 mm)	0.120" (3.0 mm)
FGP (Vinylester-Poly Thread)	6"	6.63" (168.3 mm)	6.35" (161.3 mm)	0.138" (3.5 mm)

Note 1: Not including 0.25" (6.4 mm) protective foam coating.
2: Total including 15 mm (0.6 inches) liner.